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Brad Avy, State Geologist

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# TSUNAMI EVACUATION ANALYSIS OF LINCOLN CITY AND UNINCORPORATED LINCOLN COUNTY: BUILDING COMMUNITY RESILIENCE ON THE OREGON COAST

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## GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA

*See the digital publication folder for files.*

Geodatabase is Esri® version 10.1 format. Metadata is embedded in the geodatabase and is also provided as separate .xml format files.

**Lincoln_County_Tsunami_Evacuation_Modeling.gdb:**

**XXL1_BridgesOut feature dataset:**

- XXL1_BridgesOut_EvacuationFlowZones
- XXL1_BridgesOut_EvacuationRoutes
- XXL1_BridgesOut_WalkingSpeeds_Roads
- XXL1_BridgesOut_WalkingSpeeds_Trails

**Rasters**

- MaxTsunamiFlowDepth_XXL1
- TsunamiWaveArrival_XXL1

**Metadata in .xml file format:**

Each feature class listed above has an associated, standalone .xml file containing metadata in the Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata format.

## ABSTRACT

Pedestrian evacuation routes were evaluated for a local tsunami generated by an earthquake on the Cascadia Subduction Zone (CSZ) in the following cities and communities within Lincoln County: Lincoln City, Siletz Spit, Gleneden Beach, Lincoln Beach, Seal Rock, Waldport, and Yachats. Our analyses focused on a maximum-considered CSZ tsunami event covering 100% of potential variability, termed XXL and generated by a magnitude 9.1 earthquake. Evacuation paths were limited to established roads, trails, and pedestrian pathways designated by local government reviewers as the most likely routes.

To assist in understanding pedestrian tsunami evacuation, we produced maps and digital data that include the following:

- tsunami wave advance for an XXL event,
- detailed "Beat the Wave" (BTW) results for the XXL scenario, including evacuation routes, minimum walking speeds, and evacuation flow zones,
- BTW results for multiple hypothetical scenarios, and
- socioeconomic analysis that provides insights into the unique preparation, response, and recovery challenges that communities may face due to vulnerable populations.

The BTW maps depict the ***minimum evacuation speed*** required to stay ahead of the tsunami wave given a variety of scenarios that will increase evacuation difficulty. The primary scenario uses the existing road network and includes a 10-minute delay from start of earthquake before beginning evacuation. Additional challenges to evacuation are discussed, including failure of non-retrofitted bridges and effects from landslides and liquefaction. In all cases, ***the identified minimum speeds must be maintained for the entire time it takes to evacuate from the inundation zone.***

Given the model limitations defined in the Methods section, results show that evacuation for most of the Lincoln County communities examined is achievable at a moderate walking speed (4 fps [2.7 mph]). Even for those with mobility limitations (that is, those who cannot travel at speeds more than 4 fps), safety can be reached ahead of the wave from nearly every location. Exceptions are Cutler City and Siletz Spit. For these communities, longer distances to high ground and limited evacuation routes make these especially difficult locations to reach safety prior to the arrival of the tsunami. Liquefaction could present a significant challenge to evacuation across the region.

For the purposes of this report, we refer to tsunami mitigation in terms of actions used to improve the survivability of a local community population. Thus, the results presented in this study are about evaluating ways to help move people out of the tsunami zone in the shortest amount of time possible between the start of earthquake shaking and the arrival of the tsunami. Given this context, mitigation options may include adding new evacuation routes, constructing earthquake-hardened roads (built or remodeled to withstand shaking from a major earthquake and liquefaction), enhancing tsunami wayfinding signage along core routes, and/or installing a tsunami refuge, otherwise known as a vertical evacuation structure.

# 1.0 INTRODUCTION

The objective of this study is to provide local government with a quantitative assessment of challenges affecting tsunami evacuation in select coastal communities of Lincoln County for the XXL scenario. These results are important for evaluating mitigation options such as evacuation route improvements, better wayfinding, land use planning, and potential vertical evacuation options. A similar study is available for the Lincoln County coastal community of Newport and surrounding area (Gabel et al, 2019).

A locally generated tsunami from a Cascadia subduction zone (CSZ) earthquake will inundate the Oregon coast within tens of minutes (Priest and others, 2009; Witter and others, 2011). For the majority of the population, spontaneous evacuation on foot will be the only effective means of limiting loss of life, because vehicle evacuation will be quickly compromised by traffic congestion and road blockages. CSZ earthquakes affecting the Oregon coast will likely be on the order of ~Mw 9.0 (Priest and others, 2009; Witter and others, 2011), severely damaging bridges and other infrastructure that may be critical to evacuation. To evaluate CSZ tsunami impact, Witter and others (2011) used a logic tree approach to produce a suite of deterministic scenarios, five of which are mapped statewide, each covering the following percentages of potential variability of Cascadia tsunami inundation (Priest and others, 2013b):

- Extra-extra-large (XXL1) (100%)
- Extra-large (XL1) (98%)
- Large (L1) (95%)
- Medium (M1) (79%)
- Small (SM1) (26%)

The maximum-considered CSZ tsunami (XXL1, referred to as “XXL” for much of the remainder of this report) inundates some portion of all Lincoln County communities included in this study and, in some cases, the entire community (**Figure 1-1**). North Lincoln County will start to be flooded within 20 minutes of the start of earthquake shaking; south Lincoln County is expected to be flooded in about 26 minutes.

**A Note about Bridges and Tsunami Evacuation in Lincoln County**

Bridges can further complicate tsunami evacuation if they prove to be essential to a route and are not built to withstand the shaking from the earthquake. Because of this, DOGAMI tsunami evacuation analyses include both “Bridges In” and “Bridges Out” Beat the Wave (BTW) scenario modeling. The “Bridges Out” scenario allows passage across the Millport Slough Bridge because it has been built to withstand earthquake shaking. Otherwise, modeling indicates that area bridges are not essential for tsunami evacuation (i.e., safety can be reached without needing to cross bridges). Because “Bridges In” and “Bridges Out” Beat the Wave results are similar—and in most cases identical—only “Bridges Out” results are included in this report.

To further understand the evacuation landscape, we undertook a socioeconomic analysis to assess the numbers and types of people, businesses, and critical facilities (schools, hospitals, police, and fire) in the XXL, Large (L) and Medium (M) scenario tsunami zones. To date, socioeconomic exposure analyses have been completed for the Oregon coast using only the DOGAMI Large scenario (Wood and others, 2016), which covers ~95% of potential CSZ inundation variability. By performing similar analyses for XXL and

Medium scenarios, we are now beginning to have a better understanding about the range of socioeconomic impacts the next CSZ tsunami is likely to have. To further improve our understanding of the likely socio-economic effects the next Cascadia earthquake and accompanying tsunami will have on coastal communities, DOGAMI has initiated a more comprehensive risk assessment project using the Federal Emergency Management Agency Hazus tool in order to determine more detailed exposure impact data (fatalities, injuries, buildings damaged, debris volumes etc.) for the Medium through XXL local tsunami scenarios. The timeline for these data becoming available for north coast communities is ~1-2 years.

**Figure 1-1. DOGAMI tsunami evacuation maps (2013a-f) for communities included in this study, including (top left) Lincoln City North, (top right) Lincoln City South, (bottom) Gleneden Beach. Inundation for a maximum-considered Cascadia subduction zone (CSZ) tsunami scenario (XXL) is shown in yellow, while the maximum-considered distant tsunami scenario inundation is shown in orange. Scales vary. (Note: the Cascadia scenario encompasses BOTH the yellow and orange zones.) High ground outside the XXL hazard area is green. See Witter and others (2011) for detailed explanations of the tsunami scenarios shown on these maps. Full-scale versions of these maps are available at [https://www.oregontsunami.org](https://www.oregontsunami.org).** *Figure continued on next page.*

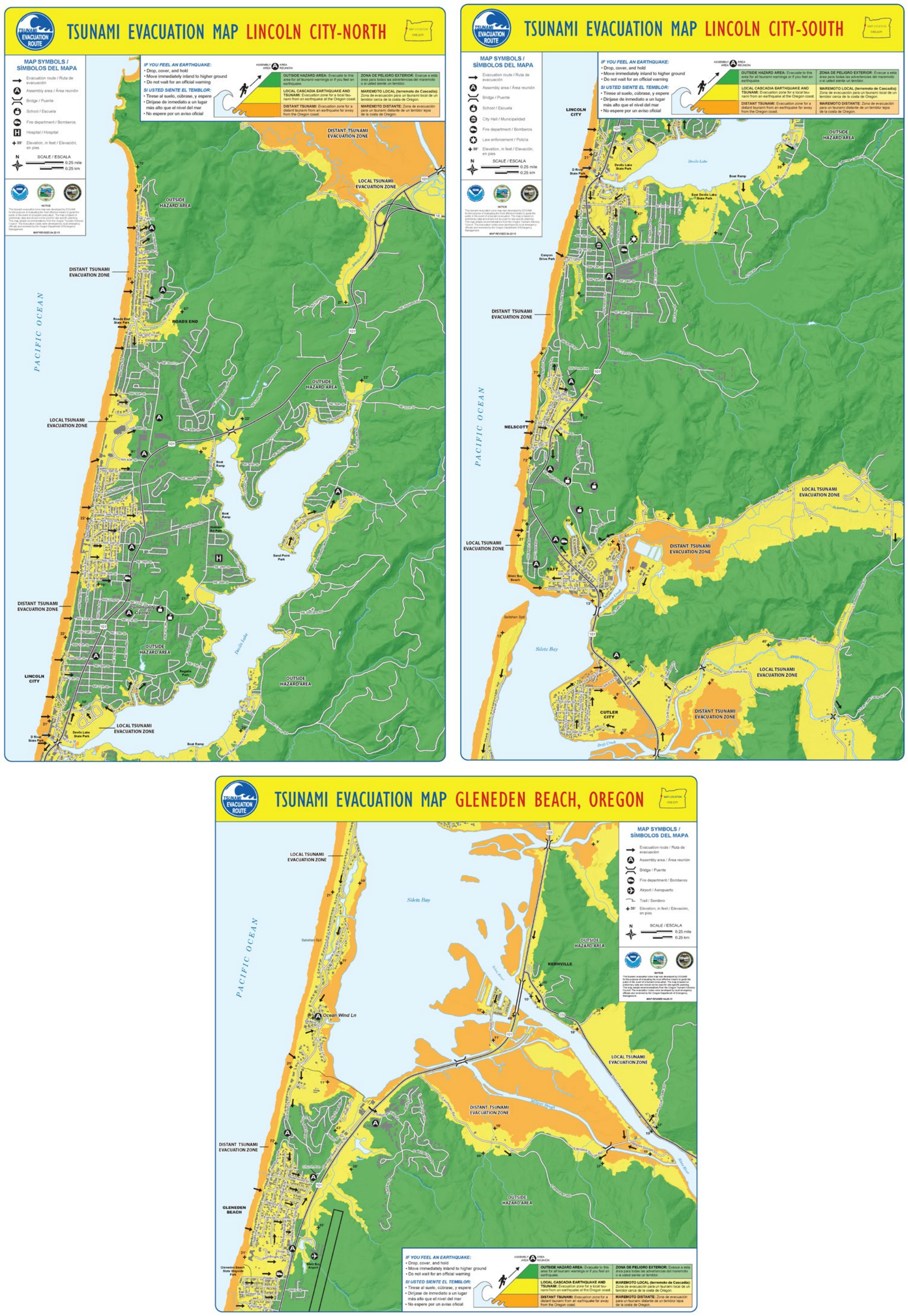
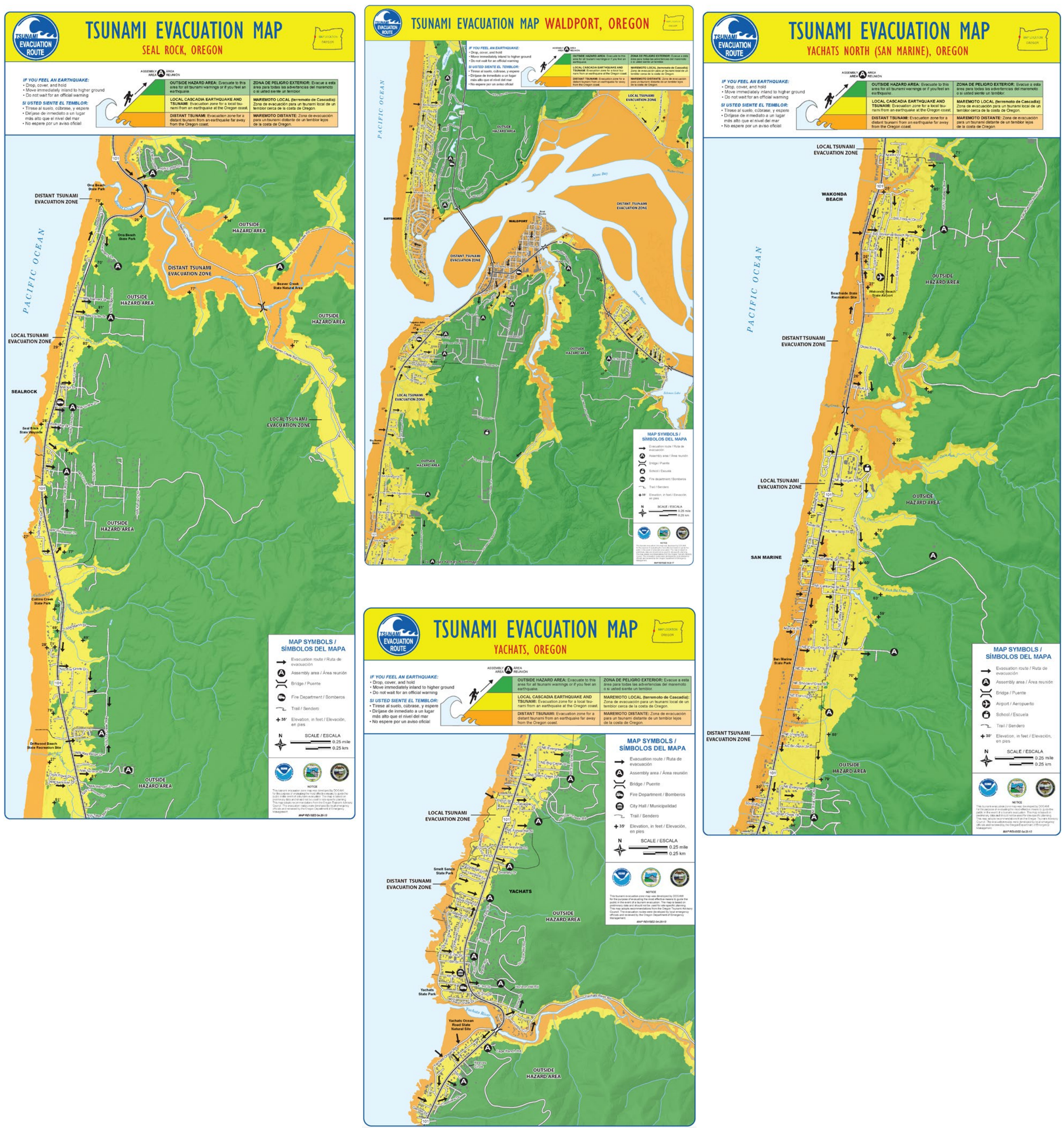


*Figure 1-1, continued from previous page.* **DOGAMI tsunami evacuation maps (2013a-f) for communities included in this study including (top left) Seal Rock, (top middle) Waldport, (top right) San Marine, and (bottom middle) Yachats. Inundation for a maximum-considered Cascadia subduction zone (CSZ) tsunami scenario (XXL) is shown in yellow, while the maximum-considered distant tsunami scenario inundation is shown in orange. Scales vary. (Note: the Cascadia scenario encompasses BOTH the yellow and orange zones.) High ground outside the XXL hazard area is green. See Witter and others (2011) for detailed explanations of the tsunami scenarios shown on these maps. Full-scale versions of these maps are available at [https://www.oregontsunami.org](https://www.oregontsunami.org).**



We evaluate tsunami evacuation difficulty by:

1. Illustrating how quickly the wave front of an XXL tsunami advances across the area after the earthquake,
2. Determining whether an evacuee can stay ahead of the tsunami all the way to safety on the routes defined by the least-cost distance (LCD) analysis, termed here as "Beat the Wave" (BTW),
3. Running multiple BTW scenarios to investigate potential vulnerabilities and mitigation options, and
4. Providing a socioeconomic analysis that provides insights into the unique preparation, response, and recovery challenges that communities may face due to vulnerable populations.

# 2.0 METHODS

Agent-based and LCD modeling are the two most common approaches for simulating pedestrian evacuation difficulty. Agent-based modeling focuses on the individual and how travel would most likely occur across various cost conditions, such as congestion points (Yeh and others, 2009). LCD modeling focuses on characteristics across the evacuation landscape, such as slope and land cover type (e.g., roads, trails, and beaches). LCD modeling calculates a least-cost path to the tsunami inundation limit for every point in the inundation zone, artificially increasing distances for non-optimal walking conditions (e.g., steep slopes, difficult land cover) and choosing the best routes accordingly. Time to traverse a route can then be estimated by dividing the least-cost path by a single pedestrian walking speed. We used the LCD model of Wood and Schmidtlein (2012) to understand better the spatial distributions of evacuation times without having to create a large number of scenarios for specific starting points required by agent-based models. BTW models integrate tsunami wave arrival data directly into the LCD analysis to produce map of ***minimum*** speeds that must be maintained to reach safety. Additional information on the methodology is given by Gabel and Allan (2017) and Priest and others (2015, 2016).

## 2.1 Road and trail network

We used a model that considered only roads, paths, and the dry sand backshore of beaches as evacuation pathways; all other land cover classes were essentially excluded. This removes the complication of crossing private property and allows us to generate informative maps. Geospatial data representing roads, pedestrian paths, and beaches were generated through manual classification of imagery, were field verified, and then were reviewed by local officials. The backshore is defined as areas landward of the beach-dune junction approximated by the 18-ft NAVD88 (North American Vertical Datum of 1988) contour. The beach (below 18 ft) was excluded owing to uncertainty of travel difficulty (cost) on wet versus dry sand and potentially liquefied sand during a local subduction zone earthquake. Due to the wide variety of beach surfaces, modeled BTW speeds on beach "trails" is intended to provide only a rough approximation of the time and speeds required to evacuate the area. We chose to ignore travel time from buildings or other parts of urban areas to the roads, because there is large uncertainty in conditions both before (e.g., fenced yards) and after the earthquake (e.g., fallen debris). Because of these assumptions and factors, the modeling approach produces ***minimum*** evacuation speeds to evacuate safely from the inundation zone.

## 2.2 Hypothetical scenarios

The evacuation landscape was first evaluated by using the existing road, trail, and bridge network. An inventory of infrastructure at risk of failure during the earthquake was collected and a suite of scenarios was developed to investigate the resulting evacuation route challenges. These include the potential failure of bridges and road blockages (slowdowns) caused by landslides or liquefaction. Additional scenarios reflecting hypothetical mitigation options were then considered to address these challenges, including constructing new trails, hardening existing roads or trails, seismically retrofitting a bridge, constructing new pedestrian and/or car bridges, and building vertical evacuation structures. In some cases, no options were considered feasible and no hypothetical scenarios were modeled. Multiple review sessions with community officials ensured local needs and concerns were addressed by the scenarios.

We simulated bridge failure by removing the bridge section of the road network, forcing the model to recalculate routes that originally relied on bridge connectivity. Which bridges to remove for the simulations was based on conversation with local officials and on information about which bridges had been designed to withstand significant seismic forces. Bridge failure typically results in longer distances to safety, either by requiring a longer route to the original safety destination or by rerouting to a completely different destination. We always begin our simulation set with a “base” run that includes all bridges. Subsequent simulations without bridges allow us to compare the results with the base run and highlights which bridges are important for evacuation. These results can be important when prioritizing which bridges to retrofit or to construct as part of a long-term resilience plan.

In coastal towns, landslide-prone slopes and saturated sandy soils are common; therefore slides, liquefaction (**Figure 2-1**, left), and lateral spreading (**Figure 2-1**, right) are likely to occur during an earthquake (Madin and Wang, 1999). These hazards will damage roads and reduce walking speeds by significant but indeterminate amounts. Because knowing where to remove routes remains highly uncertain and site specific, we did not model the effect of lateral spreading on evacuation difficulty. However, we did evaluate evacuation difficulty due to liquefaction in areas with high susceptibility (Madin and Burns, 2013). This was achieved by adjusting the land cover values to reflect loose sand instead of pavement for those roads potentially susceptible to liquefaction, thereby increasing the time it would take to evacuate along these roads; additional information describing land cover values is provided in section **2.3.3**. By identifying at-risk areas, a community can focus additional efforts on possible mitigation options like retaining walls, soil replacement, vibrocompaction, and construction of liquefaction-proof paths.

**Figure 2-1. Water-saturated sand can turn to quicksand during strong shaking, forming sand boils, ponding, and sunken roads. In these examples, (left) extensive liquefaction occurred along River Road in Christchurch, New Zealand following the February 2011 earthquake, while (right) effects from lateral spreading along numerous Christchurch roads constructed next to waterways resulted in major failures to road infrastructure as roads slumped toward river channels. During a Cascadia subduction zone event, such processes could compromise tsunami evacuation routes as well as the time and speed to safety in areas prone to liquefaction. (Photo credits: Martin Luff, licensed under CC BY-SA 2.0)**


For landslide potential, we used the Statewide Landslide Information Database for Oregon (SLIDO, version 3.4, https://www.oregongeology.org/slido/index.htm) to evaluate previously identified landslides in the area. We also considered possible landslide activity based on susceptibility mapping by Burns and others (2016). For areas where landslides have the potential to remove completely an evacuation route, we created hypothetical scenarios to reflect that. There may be areas where landslide activity may make evacuation difficult but not impossible, and in those cases, we did not always model a landslide scenario. It is also likely that the area will be dotted with smaller shallow slides (and possibly new deep-seated slides) after the earthquake; these slides could affect many roads but evaluating such landslides is beyond the scope of this study.

In some localities, safe and effective evacuation to high ground may not be feasible due to terrain challenges (high ground is too far away) or to potential failure of critical evacuation infrastructure such as bridges. Given these circumstances, communities may want to explore constructing a vertical evacuation structure, designed to withstand the forces directed at it by the tsunami. Such structures include soil berms or structures that can serve dual purposes as parking garages, community facilities, commercial facilities (e.g., hotels), and schools (Applied Technology Council, 2012). In the United States, the first vertical evacuation structure was opened in June 2016 at the Ocosta Elementary School on the Westport Peninsula in Washington State. The structure is the school's new gymnasium and has unrestricted (open) access to its rooftop, where schoolchildren and residents may congregate during a tsunami evacuation. The second of its kind in the country is currently being built at Hatfield Marine Science Center (HMSC) in south Newport, Oregon, with expected completion in 2020. We incorporate vertical evacuation structures into BTW modeling by editing the tsunami hazard zone to exclude a small polygon of safety at the location of a hypothetical structure.

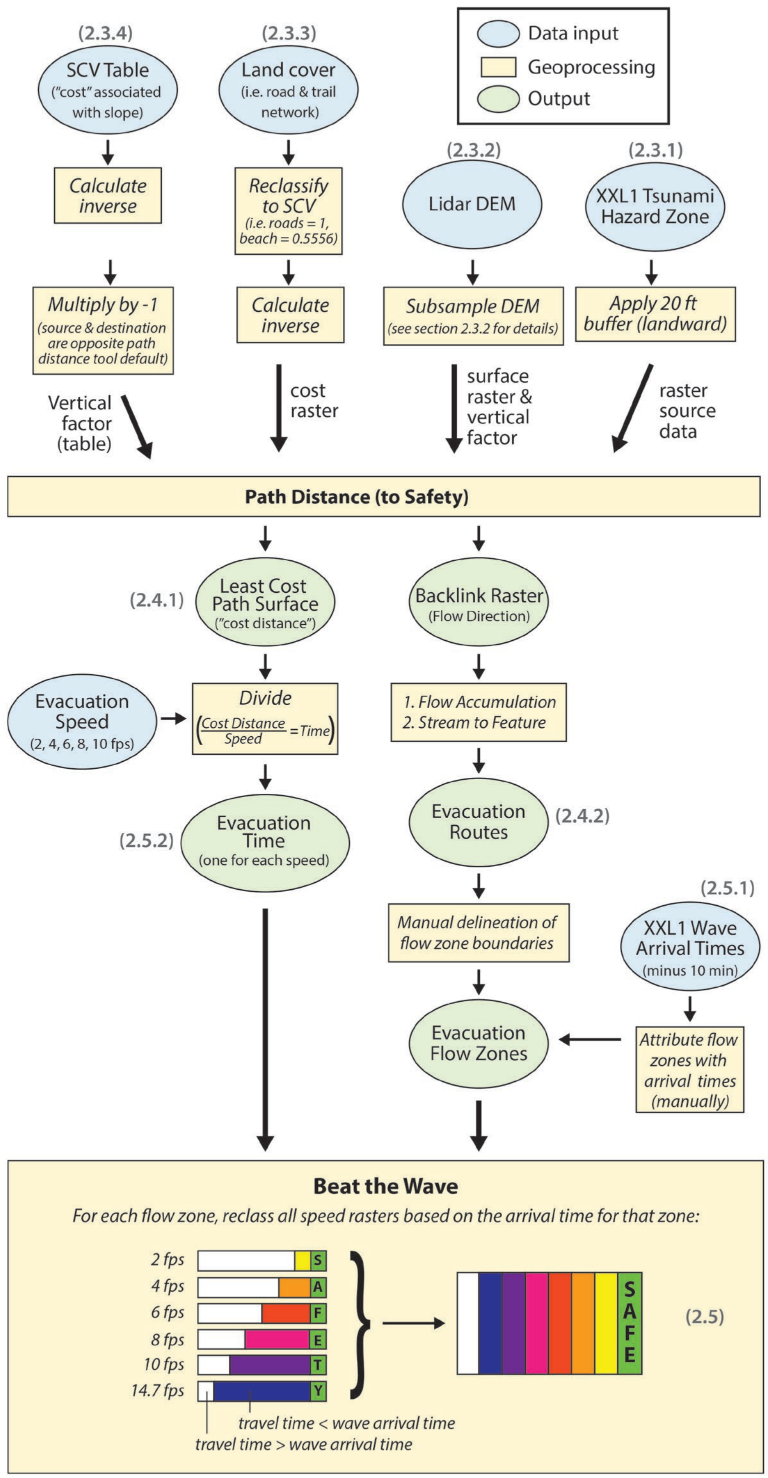
Regardless of infrastructure improvements considered for an area, wayfinding and outreach will always be an essential part of tsunami evacuation planning.

## 2.3 LCD model inputs

LCD modeling is based on four inputs: the XXL tsunami inundation limit, a digital elevation model (DEM), a land surface cost raster, and a table relating slope to cost. The road and trail network is provided via the land surface cost raster. The tsunami inundation limit (plus 20 lateral feet for conservatism) serves as the destination for all evacuation routes. The DEM is used to determine actual distances and slopes. The slope data, in conjunction with the slope table, are used to apply a cost reflecting evacuation difficulty due to hilliness. The land cost raster contains a second set of cost values reflecting evacuation difficulty due to terrain. A detailed discussion of all four inputs is presented in the following sections.

We implemented LCD modeling by using Esri® ArcGIS® 10.6 software. The path distance tool uses geospatial algorithms to calculate the most efficient route from each point in the evacuation zone to “safety,” defined for the purposes of this study as ~20 lateral feet (6 m) outside the maximum inundation limit; this is where the tsunami flow depth and velocity are effectively zero. The product of this tool is referred to as the least-cost path distance surface, and it reflects an artificial distance to safety for every point in the evacuation zone that contains the difficulty of walking that route. **Figure 2-2** summarizes the steps and inputs into the path distance tool as well as the subsequent BTW approach.

**Figure 2-2. Model diagram of Beat the Wave tsunami evacuation methodology using the path distance approach from Wood and Schmidtlein (2012) and Wood and others (2016). SCV is speed conservation value; DEM is digital elevation model. The methodology was first detailed by Priest and others (2015, 2016). XXL is the maximum-considered Cascadia subduction zone (CSZ) tsunami scenario, covering 100 percent of potential CSZ tsunami inundation (Witter and others, 2011, Priest and others, 2013b). Unit fps is feet per second. Grey numbers indicate sections in this report where a step is discussed in detail.**



### 2.3.1 Tsunami hazard zone

The inundation zone used in this study is XXL1, derived from digital data of Priest and others (2013a,b). This zone covers 100 percent of potential CSZ inundation (Witter and others, 2011), meaning it is the largest CSZ event likely to occur based on the 10,000 year record and reflects the zone used for evacuation as shown in DOGAMI evacuation brochures (https://www.oregongeology.org/tsuclearinghouse/pubs-evacbro.htm) and online (http://nvs.nanoos.org/TsunamiEvac) for the entire Oregon coast. In extreme cases where evacuation from XXL is unlikely due to long distances to safety, results are shown for the L1 tsunami scenario (Priest and others, 2013a,b). This zone covers 95% of potential CSZ inundation, meaning that there is only a 5% chance that high ground outside L1 will be inundated by a larger tsunami.

For the purposes of this study, safety is reached when an evacuee has walked ~20 feet beyond the limit of tsunami inundation. Safety is also referred to as "high ground" throughout the remainder of this report. Safety *destinations* represent locations on the road and trail network that are ~20 feet beyond the limit of inundation (primarily XXL). These locations were created by applying a buffer of 20 feet (6 m) on the landward side of the inundation boundary polyline and converting this into a raster data file.

### 2.3.2 DEM

Initially, we created a high-resolution digital elevation model (DEM) by interpolating lidar ground points into a 6-ft-resolution raster; in areas characterized by bridges, we used lidar highest-hit data to define the bridge walking surface. We smoothed the DEM grid, because generated slope profiles are too noisy, introducing slope artifacts of significant amplitude (e.g., a 3-inch elevation difference between cells 1 foot apart yields a 14° slope) that add substantially more time to the total calculated time (Priest and others, 2015, 2016). To smooth the data, we created points at 50-foot intervals along all evacuation paths including major roads and at intersections, and we attributed those points with elevation values from the native 3-foot-cell lidar DEM. Priest and others (2015, 2016) performed trials at 25, 50, and 100 feet and found that the 50-foot interval achieved the best compromise between accuracy and smoothness. The final sampling interval was ~50 feet on straight paths and somewhat less for curved paths in order to depict accurately the curvatures. We then interpolated those points using an Esri Natural Neighbor function to produce a smoothed DEM that closely emulated the actual elevation values of the lidar while dramatically reducing slope noise.

### 2.3.3 Land cover raster

The land cover raster serves two purposes: 1) it defines the spatial extent of the road and trail network, and 2) it describes the land cover for all surfaces in the region, by assigning a specific level of difficulty of movement across the surface for each pixel. In the Wood and Schmidtlein (2012) approach these difficulty or cost values are categorized as speed conservation values (SCV), where each value is representative of a land cover type across the landscape. Land cover SCVs adjust the base travel speed by using terrain-energy coefficients as discussed by Soule and Goldman (1972), including "No Data" to note where travel is not allowed (e.g., over water, through fences or buildings, and across most natural/undeveloped areas for this study). The base travel speed assumes constant energy expenditure. Conversely, the constant energy expenditure assumption yields slower walking speeds under non-ideal walking conditions. Ultimately, the SCVs artificially increase the path distance across a pixel (6 ft) to reflect the difficulty in walking that section of road or trail. The SCV values used are shown in **Table 2-1**, and an example land cover raster is shown in **Figure 2-3**.

**Table 2-1. Speed conservation values used in modeling pedestrian evacuation difficulty in this study.**

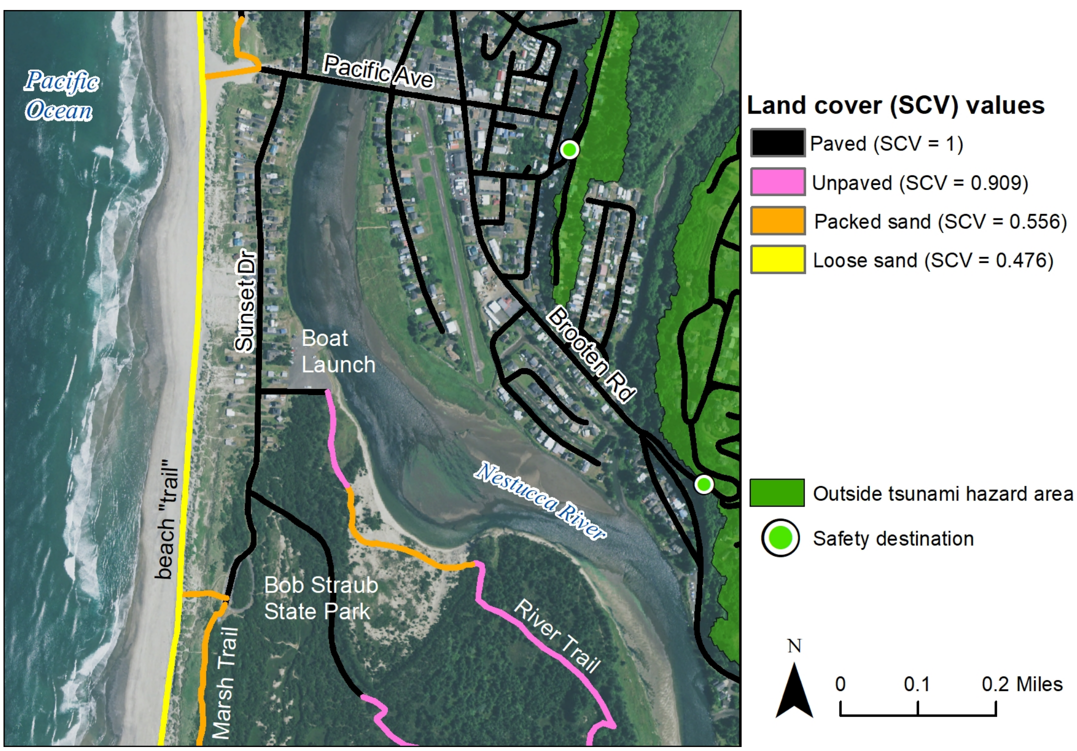
| Feature Type | Speed Conservation Value* |
|---|---|
| Roads (paved surface) | 1 |
| Unpaved trails | 0.9091 |
| Dune trails (packed sand) | 0.5556** |
| Muddy bog | 0.5556 |
| Beaches (loose sand) | 0.476 |
| Everywhere else | 0 |

*Speed conservation values (SCV) are derived from Soule and Goldman (1972).

**Trails in the dune areas given the same SCV as sand given by Wood and Schmidtlein (2012).

GIS polylines representing all roads and trails in the project area were converted to polygons and attributed with land cover values (i.e., 1 for paved surfaces, 0.556 for packed sand, etc.). The polygons were then converted into a raster (6 ft cell size) for input into the LCD model.

**Figure 2-3. Example of a land cover raster in Pacific City, Tillamook County, Oregon, which serves the dual purpose of defining the road and trail network and classifying it with land cover values. Base map is 2016 National Agriculture Imagery Program (NAIP) imagery; the XXL inundation zone (the non-green area) on this and following figures is from Priest and others (2013b).**



### 2.3.4 Speed conservation value (SCV) slope table

We created a table that associates slopes with a specific SCV value. This table uses the same values as those of Wood and Schmidtlein (2012), and, as in their approach, we estimated the effect of slope on speed from Tobler's (1993) hiking function:

$$\text{walking speed (km/hr)} = 6e^{-3.5 \times \text{abs(slope+0.05)}}$$

where slope is equal to the tangent of the slope angle. This formula is based on empirical data of Imhof (1950) and predicts that speed is fastest on gentle (−3°) downslopes. **Table 2-2** presents an example set of slope and SCV values. The actual table used includes slope values from −90° to +90° in 0.5° increments. A positive slope (upward) results in a slower walking speed and is assigned a larger cost. The same applies for a large negative slope (steeply downward), while a slight decline (~3°) in the slope reflects the optimal condition.

**Table 2-2. Speed conservation values used to calculate evacuation difficulty due to traversing hills, with slope determined for each pixel from the digital elevation model.**

| Slope (degrees) | Tobler (1993) Walking Speed (fps) | Speed Conservation Value* |
|---|---|---|
| −10 | 3.6 | 1.5 |
| −5 | 4.8 | 1.1 |
| −2.75 (ideal) | 5.5 | 1 |
| 5 | 3.4 | 1.6 |
| 10 | 2.5 | 2.2 |

*Table displays an example set of values. Actual table used in modeling includes slope values from −90° to +90° in 0.5° increments. fps is feet per second.

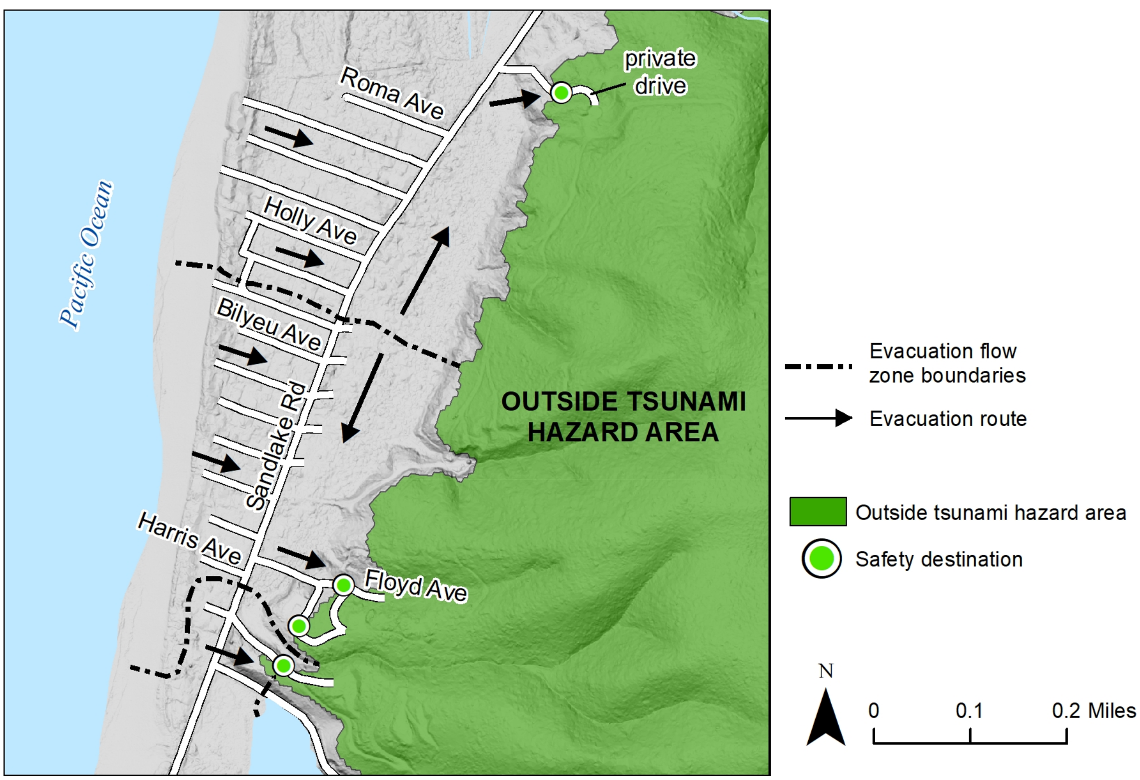
## 2.4 LCD model outputs

The LCD model outputs a path distance surface showing the effective distance to safety from each pixel and a flow direction raster containing detailed route information. From these data we create evacuation route, flow zone, and BTW maps.

### 2.4.1 Path distance surface

The pixel values on the path distance surface represent the effective distance, along the least-cost path, from the pixel to the point where the path intersects safety. For example, from the intersection of Sandlake Road and Bilyeu Avenue in Tierra Del Mar (**Figure 2-4**), the actual distance to safety up Floyd Avenue is 1,700 feet, while the least-cost path distance is 2,700 feet (path distances not shown on map). This difference is due to the model accounting for variations in slope and landcover along the entire route (although in this case the entire route is paved, meaning the cost is entirely due to the significant slope on Floyd Avenue).

**Figure 2-4. Example of a network of generalized evacuation flow zones and select evacuation route arrows from a least-cost-distance analysis limited to trails and streets in Tierra Del Mar, Tillamook County, Oregon. Base map on this and subsequent figures is shaded relief from 2009 lidar data (Oregon Lidar Consortium North Coast Project, https://www.oregongeology.org/lidar/index.htm).**



### 2.4.2 Evacuation routes and flow zones

The LCD backlink raster shows, for each cell, the direction of the next cell on the least-cost path. This raster makes it possible to trace the path to safety from any pixel and is equivalent to a flow direction raster, which is the first step in hydrologic modeling of topographic surfaces. We use the hydrologic tools in ArcGIS 10.6 and the backlink raster to extract a "stream" network to visualize the paths depicting the most efficient pedestrian flow for evacuation on trails and roads. Evacuation flow zones with arrows depicting the most efficient routes are shown in **Figure 2-4**. These paths represent the shortest effective distances to the nearest safety destination and are referred to as evacuation routes. **Figure 2-4** shows what we call "generalized evacuation routes," meaning the arrows illustrate the overall direction of travel toward a safety destination and are not turn-by-turn directions. Detailed evacuation routes are found in the digital data.

The routes can be simplified by identifying the boundaries of evacuation flow toward the nearest safety location. At these boundaries, one could travel in alternate directions to reach safety on separate paths that require equal amounts of effort (distance with slope and land cover effects included). These evacuation flow zones are directly analogous to watershed boundaries or drainage divides in hydrologic modeling. As an example, **Figure 2-4** shows that the nearest safety destination for people on Bilyeu Avenue in Tierra Del Mar is Floyd Avenue while the nearest safety destination for people on Holly Avenue is a private drive off Sandlake Road north of town. The dashed black line delineates the evacuation flow zone boundary.

We manually drew the flow zone polygons using the evacuation routes as a guide. Flow zone rasters can also be generated by using the Esri Watershed tool in the Hydrology toolset; however, we found this method useful as a guide only, not as a source of functional data.

The importance of flow zone boundaries varies depending on the area. In some areas, so many roads head toward high ground that the decision to take one road versus another is minor. In other locations, flow zone boundaries inform the decision to travel in potentially opposite directions (for example, **Figure 2-4**).

## 2.5 Beat the Wave (BTW) modeling

BTW modeling integrates the results of the tsunami wave arrival times and the least-cost path distance analyses to enable the public to better understand the ***minimum speeds*** required to evacuate the inundation zone to avoid being caught by the approaching tsunami. BTW modeling is done by producing a suite of evacuation time maps at different walking speeds and combining them into one map based on unique wave arrivals for each evacuation flow zone. The goal of BTW maps is to highlight areas that have greater evacuation difficulty in order to direct future mitigation efforts and educate the public on where to go and how fast to travel.

### 2.5.1 Wave arrival times

To understand the complexities of tsunami wave advance across the landscape, we extracted the time after the CSZ earthquake at which the XXL tsunami flow depth reached more than 0.5 ft (6 inches) at each computational grid point and interpolated those arrival data to create a continuous map showing wave arrival time.

Wave arrival times were then assigned to each evacuation flow zone based on the time when the first wave reaches the *point of safety* for each zone. Depending on the safety destination, this time can be less than 15 minutes to more than 30 minutes after the tsunami first reaches land. We then subtracted 10 minutes from the simulated tsunami arrival times to account for the time in which earthquake shaking takes place, as well as disorientation, and the time required to evacuate buildings. Using the March 11, 2011, Tohoku earthquake (U.S. Geological Survey, 2012) as an analogue to an XXL or L1 scenario, the minimum delay is probably ~3–5 minutes of strong shaking for an ~Mw 9.0 event. There are few empirical data on how long it takes people to begin evacuation after shaking, but Mas and others (2013) determined a mean of 7 minutes in 2010 and 2011 surveys at La Punta, Peru, which has experienced several local earthquakes and tsunamis over the last ~400 years, the last being in 1974. We therefore simulate a delay of 10 minutes mainly for earthquake shaking (the minimum of 3 minutes for shaking plus 7 minutes based on the La Punta survey). This is a rough estimate meant to account for many possible actions taken by evacuees such as looking for family members, digging out of rubble, or packing a bag prior to evacuating.

For areas with large campgrounds and few to no permanent residents, we reduced the delay from 10 minutes to 5 minutes to reflect the likelihood of people being outdoors (or inside an RV or tent) when the earthquake begins. We anticipate a shorter delay between earthquake shaking and evacuating for someone in a tent or RV compared with someone in a building.

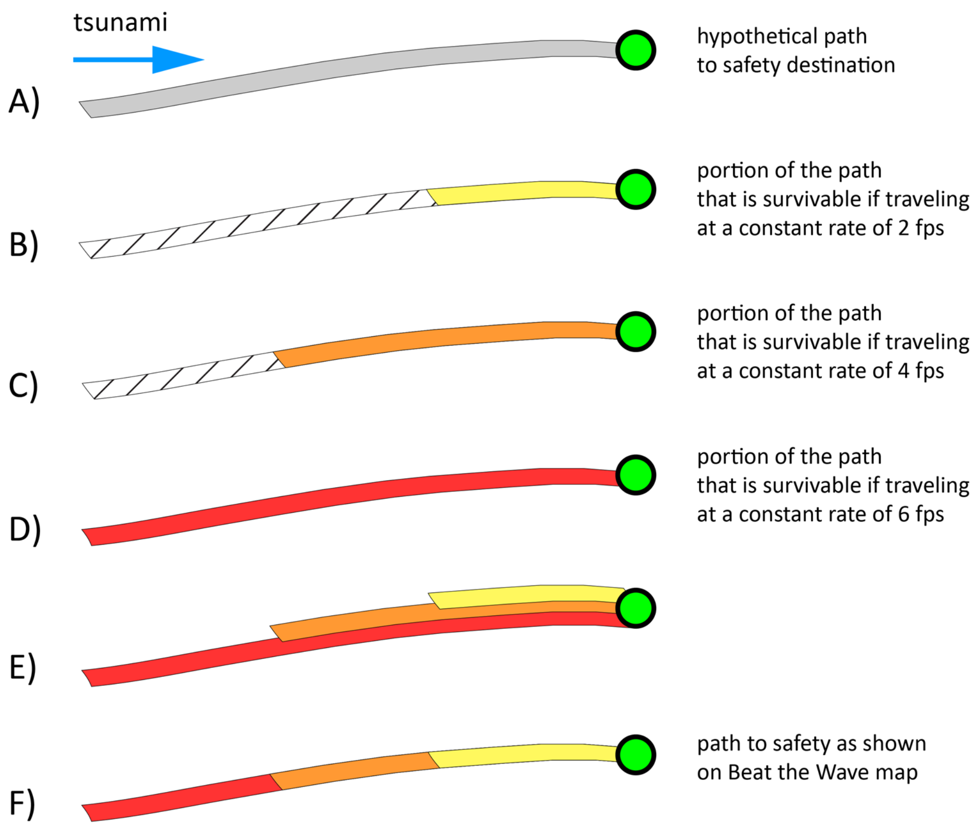
### 2.5.2 Evacuation time maps

We converted the path distance surfaces to walking times to compare tsunami arrival times to pedestrian arrival at various critical junctures. We did this by dividing the path distance surface raster by a constant speed (distance ÷ speed = time). We started by assuming a pedestrian walking speed of 4 feet per second (fps) (22 minutes/mile; 1.22 meters/second), a pace listed as a moderate walk by Wood and Schmidtlein (2012). This is the speed generally required to cross from curb to curb at signalized intersections (Langlois and others, 1997; U.S. Department of Transportation, 2012).

In order to fully explore an array of evacuation speeds appropriate for specific populations (e.g., elderly or small children versus able-bodied adults) we generated multiple evacuation time maps using pre-determined evacuation speeds (2, 4, 6, 8, 10, and 15 fps). We then “clipped”[1] these time maps twice: once to separate flow zones and again based on the unique wave arrival time for each zone. For each evacuation speed within a flow zone, the surface was clipped at the point where the time to reach safety was greater than the wave arrival time. These clipped grids were then mosaicked together, with the minimum speed for each cell maintained. These steps are described graphically in **Figure 2-5** and in the final step of **Figure 2-2**. By integrating evacuation time maps with tsunami wave arrival data, we can now produce Beat the Wave (BTW) maps that estimate the ***minimum speed*** needed to reach safety ahead of the wave.

[1] “Clip” is a GIS command that “extracts features from one feature class that reside entirely within a boundary defined by features in another feature class” (https://support.esri.com/en/other-resources/gis-dictionary).

**Figure 2-5. Illustration of Beat the Wave (BTW) tsunami evacuation map construction. (A) shows a hypothetical evacuation route. (B), (C), and (D) show the path with constant walking speeds of 2 fps, 4 fps, and 6 fps, respectively. The farther away from safety (green dot) evacuees begin the route, the faster they must walk at a constant rate to reach safety ahead of the tsunami. At 2 fps only a relatively small amount of the route is survivable (hashed areas denote unsurvivable sections of the path at given walking speed); however, at faster walking speeds, evacuees can cover more distance and reach safety if they maintain the initial walking speed. (E) displays how the different constant walking speeds are combined to create the (F) final BTW map. The BTW map shows minimum constant speeds necessary to reach safety ahead of the tsunami.**



Evacuation speeds were initially grouped into five categories, which allow enough contrast in color choice that areas can be easily perceived on the map. A literature review of typical pedestrian speeds by Fraser and others (2014) found five travel speed groups: adult impaired, adult unimpaired, child, elderly, and running (**Table 2-3**). The ranges of speeds for these groups at one standard deviation (the last two rows of **Table 2-3**) provide some guidance for establishing bins that would be useful on the BTW map. We then gave speed categories in the map explanation qualitative names such as “slow walking” and “running,” so the public could relate speed bins to their experience. Of particular interest are population groups that will be most vulnerable, such as impaired adults and the elderly, with mean speeds of 3 fps and a range of ~2–4 fps (**Table 2-3**). In an earlier Seaside BTW study (Priest and others, 2015) we examined the range of BTW speeds and reviewed a number of references describing speed categories (Paul, 2013; Margaria, 1968) to settle on the following five speed bins:

- Very slow walking at 0–2 fps
- Slow walking at 2–4 fps for elderly and impaired adults
- Walking at 4–6 fps for unimpaired adults
- Fast walking to slow jogging at 6–8 fps for fit adults
- Running at >8 fps

However, for extremely long path distances and fast wave-arrival times, we further divided the highest bin (>8 fps) into three bins to understand better the likelihood of survivability:

- Running at 8–10 fps
- Sprinting at 10–14.7 fps (14.7 fps = 10 mph)
- Unlikely to survive (must sprint at > 14.7 fps)

A small experiment was conducted at Seaside to evaluate the validity of the ***walk***, ***fast walk***, and ***slow jog*** BTW evacuation speed bins and to assess the difficulty in maintaining a constant minimum speed over the course of an entire evacuation route (Gabel and Allan, 2016). Five key routes were traversed by Gabel and Allan, who recorded their average speed along the route and the times when they reached critical locations (bridges, low areas, and safety). Overall, the tests indicated that when traveling at the speed specified by the BTW data, an evacuee will reach safety ahead of the tsunami. However, as speeds fall below the prescribed BTW speeds, the results of Gabel and Allan confirmed that the tsunami could overrun the individual. This limited test of BTW data suggests that the data are reasonable guides to minimum evacuation speeds necessary to reach safety ahead of the tsunami.

**Table 2-3. Travel speed statistics for each travel speed group, compiled from travel speeds in the literature by Fraser and others (2014). Symbol σ denotes standard deviation.**

| | Adult Impaired | Adult Unimpaired | Child | Elderly | Running |
|---|---|---|---|---|---|
| Minimum | 1.9 fps | 2.9 fps | 1.8 fps | 0.7 fps | 5.9 fps |
| Maximum | 3.5 fps | 9.2 fps | 6.9 fps | 4.3 fps | 12.6 fps |
| Mean | 2.9 fps | 4.7 fps | 4.2 fps | 3.0 fps | 9.1 fps |
| σ | 0.6 fps | 1.6 fps | 2.6 fps | 1.0 fps | 3.3 fps |
| Mean + 1σ | 3.5 fps | 6.3 fps | 6.8 fps | 4.0 fps | 12.4 fps |
| Mean − 1σ | 2.3 fps | 3.1 fps | 1.6 fps | 2.0 fps | 5.8 fps |

### 2.5.3 Reading a BTW map

As previously stated, the modeling approach produces ***minimum*** evacuation speeds that must be maintained along the entire route to safety. Actual travel speeds on any evacuation route will require either variable expenditure of energy to maintain a constant speed in all conditions, or higher speeds in easier terrain (flat paved streets) to compensate for slower speeds in more difficult terrain (e.g., steep slopes or sand).

BTW map colors represent the speed that must be **maintained** from each location **all the way** to safety. If an evacuee slows down for some portion of the route, they must make up the time deficit by traveling faster than the required speed for the remainder of the route. We stress this point because the map can be misleading: as a route approaches safety the roads along which one travels show a slower BTW speed, but an evacuee cannot slow down. The slower speed is only relevant for someone starting evacuation from that closer location.

## 2.6 Socioeconomic analysis

We compiled socioeconomic data that provide insights into the unique preparation, response, and recovery challenges that communities may face from a CSZ tsunami. For summarization purposes we used the boundaries contained in the U.S. Census Bureau census-designated places (CDP) GIS dataset (U.S. Census Bureau, 2010). For incorporated cities, the CDPs use established city boundaries. For unincorporated communities, the U.S. Census Bureau developed boundaries that contain a concentration of population. The socioeconomic figures and tables in this report used the CDP GIS dataset. We note that within Oregon, CDPs are non-legal entities and are for statistical summarization purposes.

DOGAMI processed geocoded Department of Motor Vehicles (DMV) driver license records to quantify the overall number and age category of permanent residents in the tsunami zone. We used the 65 and over years of age as a single breakpoint to establish the percentage of the older population in the tsunami zone. Past studies have noted that older people tend to evacuate at slower rates or are more likely choose not to evacuate, compared to people under 65 years of age (González-Riancho and others, 2015). For each community we quantified the number of people per tsunami zone (Medium, Large, XXL) and the percentage of the people in the zone who are 65 or older.

We obtained selected data from American Community Survey (ACS) 2013–2017 five-year averaged estimates (https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2017/). The ACS data are available at a city and CDP level. We note that the ACS data are presented for the entire community and not available by tsunami zone. Given that the ACS relies on statistical sampling, we include the 90% uncertainty boundaries to emphasize the uncertainty present in each estimate. In general, smaller communities have a wider range of uncertainty for each estimate. The two primary community characteristics we obtained were the number of people with disabilities and the number of households in which Spanish is primarily spoken (American Community Survey Tables S1810 [Disability Characteristics], and S1602 [Limited English Speaking Households], respectively [U.S. Census Bureau, 2018]).

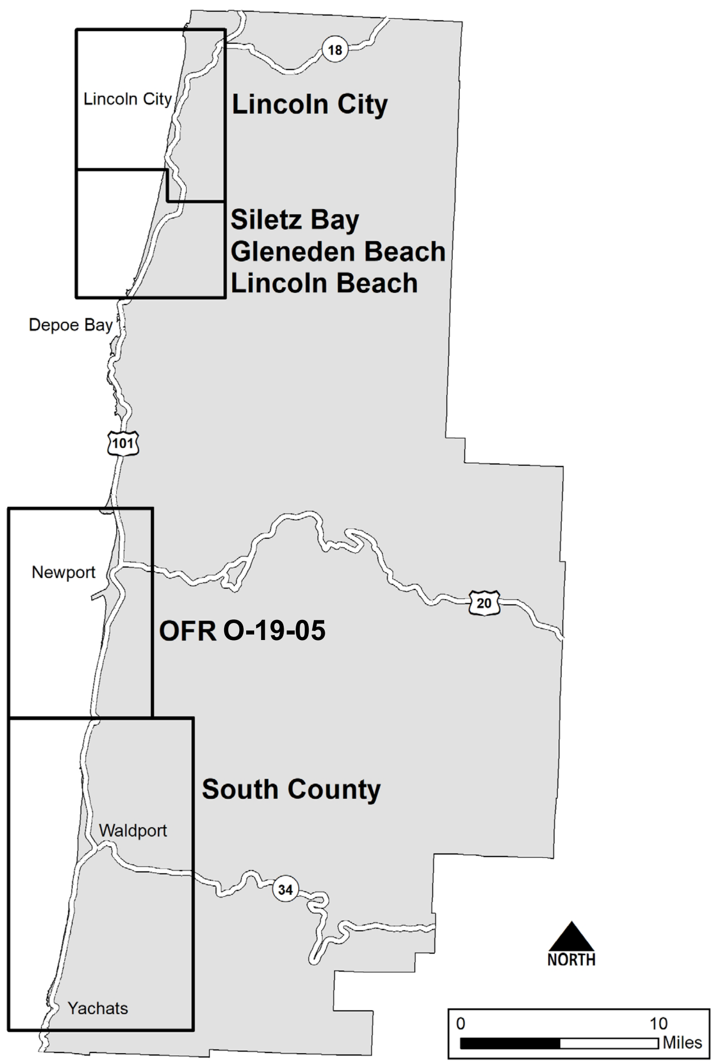
The replacement costs of buildings were obtained from detailed per-building databases constructed for ongoing DOGAMI risk assessments (M. Williams, DOGAMI, written communication, 2019). We did not model building damage from a particular tsunami scenario; rather, we quantified the total replacement cost of the buildings for the entire community and for the buildings within the community's tsunami zone. Generally, given the predominance of light-frame construction in Oregon coastal communities and the hydraulic forces contained within in a CSZ-generated tsunami, overall building damage within a tsunami zone is likely to be extensive to nearly complete (J. Bauer, oral communication, 2019). We quantified the percentage of the communities' overall building replacement cost that is within the tsunami zone.

Geocoded Quarterly Census of Employment and Wages (QCEW) data obtained from Oregon Employment Division (written communications; dataset dated September 25, 2018) were used to quantify the overall number of employers, jobs, and annual wages paid in the community and within the tsunami zone. The QCEW data were also queried to identify the largest employment sector, by number of jobs, within each community's tsunami zone. Where needed, we limited reporting on selected data to honor the employer privacy restrictions outlined in our QCEW data sharing agreement. A more detailed description of methods used for socioeconomic analysis will be available in a report from a study underway at DOGAMI (John Bauer, oral communication, 2019).

# 3.0 RESULTS AND DISCUSSION

This report covers the communities of Lincoln City, Gleneden Beach, Lincoln Beach, Seal Rock, Waldport, and Yachats (**Figure 3-1**). A BTW analysis of Newport and South Beach was completed earlier this year (Gabel and others, 2019). Section 3.1 presents our tsunami evacuation analysis (Beat the Wave) including detailed wave arrivals. A brief socioeconomic analysis follows in section 3.2. A FEMA Hazus-based analysis of building loss and casualties for five Oregon coastal communities (Gearhart, Rockaway Beach, Lincoln City, Newport, and Port Orford) resulting from a CSZ tsunami is underway at DOGAMI (John Bauer, oral communication, 2019).

**Figure 3-1. Lincoln County, Oregon, project area map. Results will be discussed separately for the three sections shown: 1) Lincoln City, 2) Siletz Bay, Gleneden Beach and Lincoln Beach, and 3) South County, which includes the communities of Seal Rock, Waldport, and Yachats. OFR O-19-05 indicates the area covered by an earlier DOGAMI open-file report (Gabel and others, 2019).**



## 3.1 Beat the Wave

In general, we find that evacuees in much of Lincoln County can escape a maximum-considered Cascadia tsunami by walking at a minimum speed of 4 fps (***walk***). Notable exceptions are Cutler City, Siletz Spit, Siletz Keys, and Alsea Spit. In these locations, evacuees must travel a significant distance to reach the nearest safety destination and must travel at faster minimum speeds to survive.

BTW evacuation modeling results for a "base" run reflecting the existing road and trail network will be presented for each community. Bridges are deemed passable if they are known to have been built or retrofitted to withstand the shaking of a Cascadia earthquake. If that is not the case, base run results will not allow passage across a bridge. When applicable, hypothetical scenarios such as liquefaction, evacuation trails, vertical evacuation structures, and bridge retrofits are included. Results are shown for a path on the beach itself and are included in the digital GIS deliverables but will not be discussed in the report. Detailed wave arrivals will also be presented for each community. In most communities, evacuation flow zones are shown on their own for the base scenario to identify which safety destination is ideal for each area of a community. Planners and local decision-makers may find this a useful tool to assist with mitigation efforts including signage and evacuation drills. Base BTW results and tsunami arrival data can be found in the Lincoln_County_Evacuation_Modeling geodatabase.

All scenarios include a 10-minute delay before commencing evacuation to account for the expected disoriented state of people following severe earthquake shaking, and the time required to exit buildings. **Table 3-1** represents a summary of the range of speeds and their conversions that will be used throughout the remainder of this report. Tsunami wave arrival figures do not include this delay.

One important note—it is inevitable that following a disaster other factors will contribute to impede travel times. This modeling does not account for these ancillary effects. As a result, ***the public should maintain the overarching goal of immediately evacuating after the earthquake and moving as rapidly as possible in order to ensure they reach safety with ample time to spare.***

**Table 3-1. Pedestrian evacuation speed categories and their conversions.**

| Description | Feet per Second (fps) | Miles per Hour (mph) | Minutes per Mile |
|---|---|---|---|
| Slow walk | >0–2 | >0–1.4 | >44 |
| Walk | 2–4 | 1.4–2.7 | 44–22 |
| Fast walk | 4–6 | 2.7–4.1 | 22–14.7 |
| Jog | 6–8 | 4.1–5.5 | 14.7–11 |
| Run | 8–10 | 5.5–6.8 | 11–8.8 |
| Sprint | 10–14.7 | 6.8–10 | 8.8–6.0 |
| Unlikely to survive | >14.7 | >10 | <6.0 |

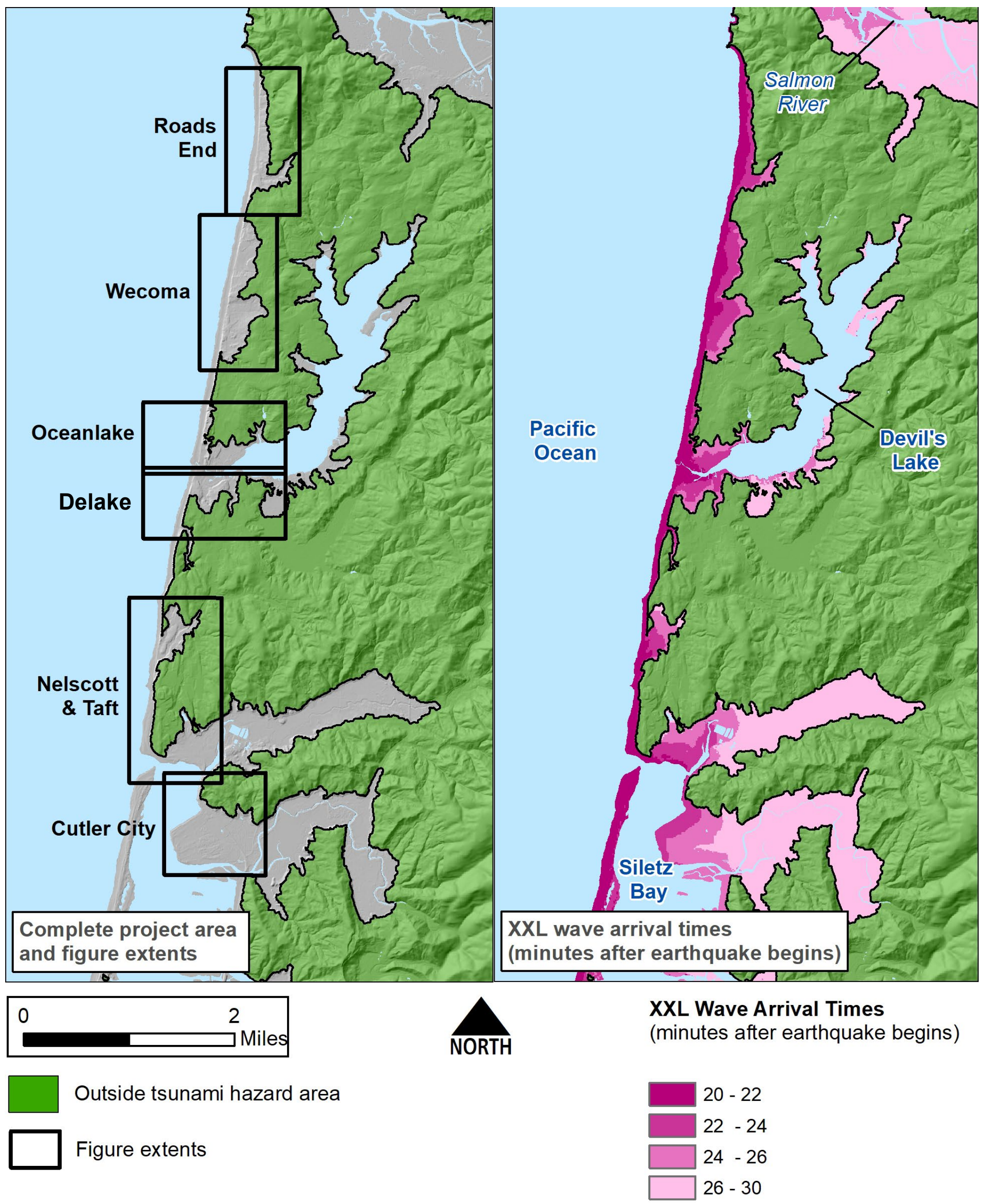
Note: walking at speeds of 2–4 fps is considered a reasonable measure for the elderly and for adults who may be mobility impaired (see Figure 6 of Fraser and others, 2014).

### 3.1.1 Lincoln City

Lincoln City is a collection of neighborhoods, each with its own unique evacuation landscape. Results will be discussed separately for each, as outlined in **Figure 3-2, left**. **Figure 3-2, right** shows the estimated arrival times for an XXL tsunami in Lincoln City. The earliest wave arrivals are along the open coast; the tsunami reaches the beach ~20–22 minutes after the start of the earthquake shaking. By 26 minutes, much of the study area is expected to be inundated. Detailed wave arrival figures are provided for each neighborhood. Tsunami wave arrival time data are found in the Lincoln_County_Tsunami_Evacuation_Modeling geodatabase, TsunamiWaveArrival_XXL1 dataset.

Overall, Lincoln City has a significant amount of accessible high ground and a positive evacuation outlook, with evacuees from nearly every neighborhood able to reach safety at 4 fps or less (***walk***) even when liquefaction (where applicable) is taken into consideration. The exception to this is Cutler City, which has some additional challenges due to its location along Siletz Bay. Walking speeds on the roads and trails as well as evacuation flow zone data for the base scenario are found in the Lincoln_County_Tsunami_Evacuation_Modeling geodatabase, XXL1_BridgesOut feature dataset.

**Figure 3-2. (left) Lincoln City area map showing figure extents. (right) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Lincoln City.**



#### *3.1.1.1 Roads End*

Roads end is characterized by a narrow inundation zone with virtually every east-west road reaching high ground within 300-400 feet of Logan Road, the main road into the neighborhood. The one exception to this is Sal La Sea Drive, which follows Logan Creek upstream and remains inside the XXL inundation zone for 0.4 miles.

**Figure 3-3, left** demonstrates tsunami arrival times for an XXL tsunami in the Roads End area. The tsunami reaches the beach ~20 minutes after the start of earthquake shaking and has flooded the narrow inundation zone by 24 minutes. **Figure 3-4** presents BTW results for a base run in Roads End. The entire neighborhood can reach safety ahead of the tsunami at a minimum walking speed of ***slow walk*** (2 fps or 1.4 mph) (**Figure 3-4, left**). **Figure 3-4, right** presents evacuation flow zones for Roads End. These define the nearest safety dsetination for everyone in the neighborhood and may be useful for personal evacuation route planning as well as community-wide wayfinding efforts. Because of the many east-west streets intersecting high ground, Roads End is characterize by numerous evacuation flow zones.

Overall, BTW results in this neighborhood are favorable and suggest a limited need for large-scale mitigation efforts such as new evacuation trails or a vertical evacuation structure. No hypothetical scenarios were modeled due to a low risk of liquefaction and landslides impacting evacuation; nor is there a reliance upon potentially compromised infrastructure such as a bridge. Despite the short distances to safety, clear and plentiful wayfinding signage is always important to direct people in the right direction during a time of panic and confusion.

**Figure 3-3. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for (left) Roads End, (right) Wecoma.**

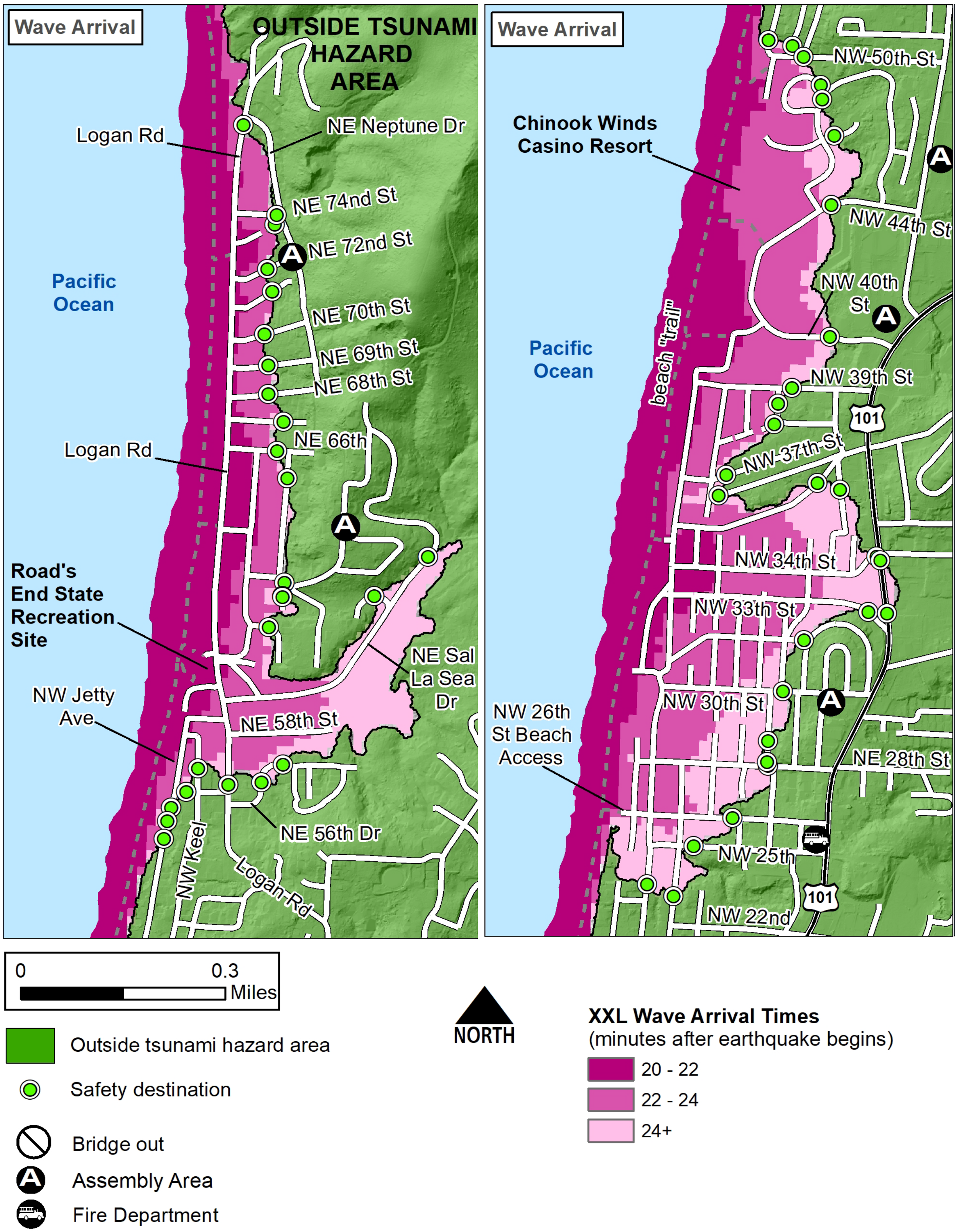
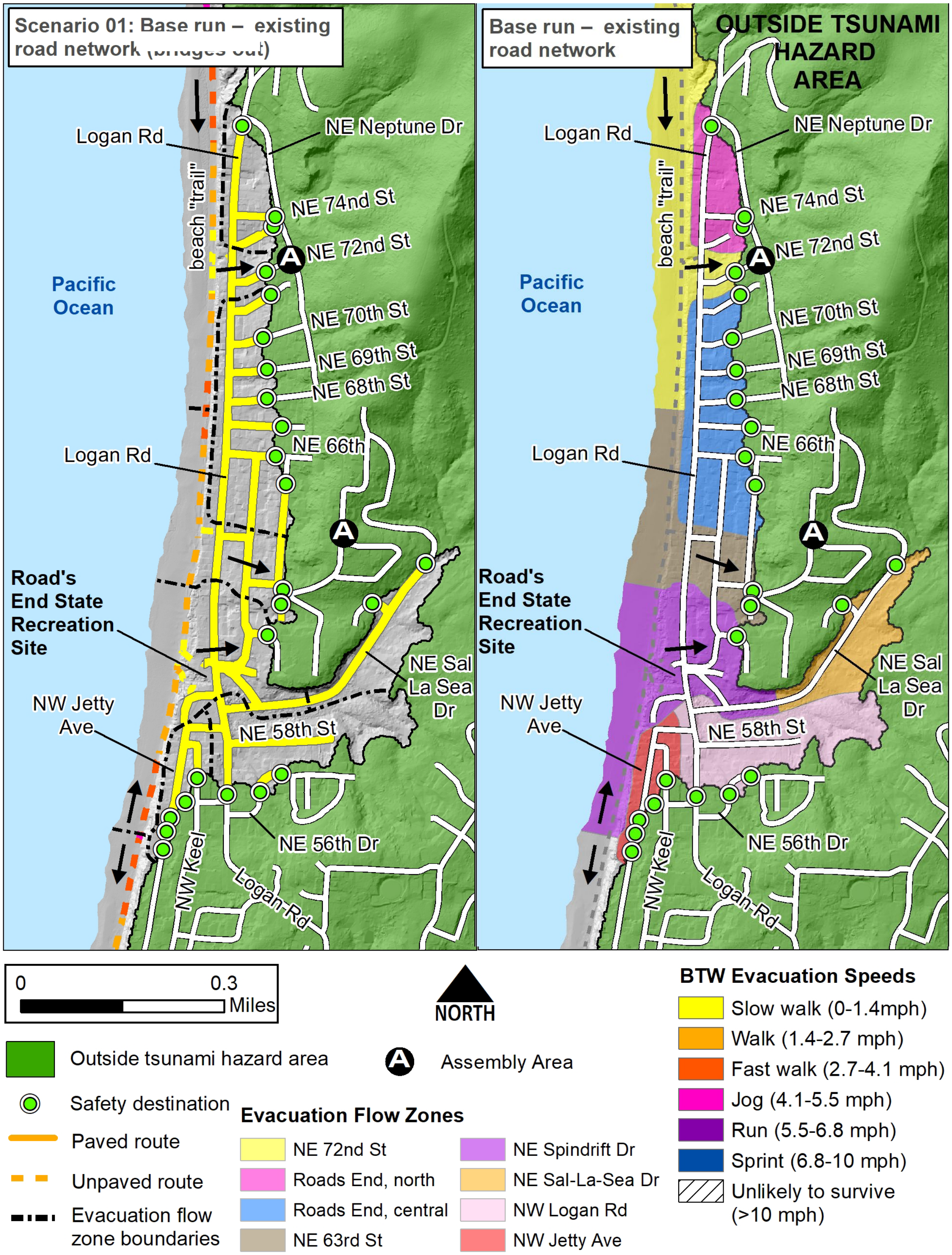


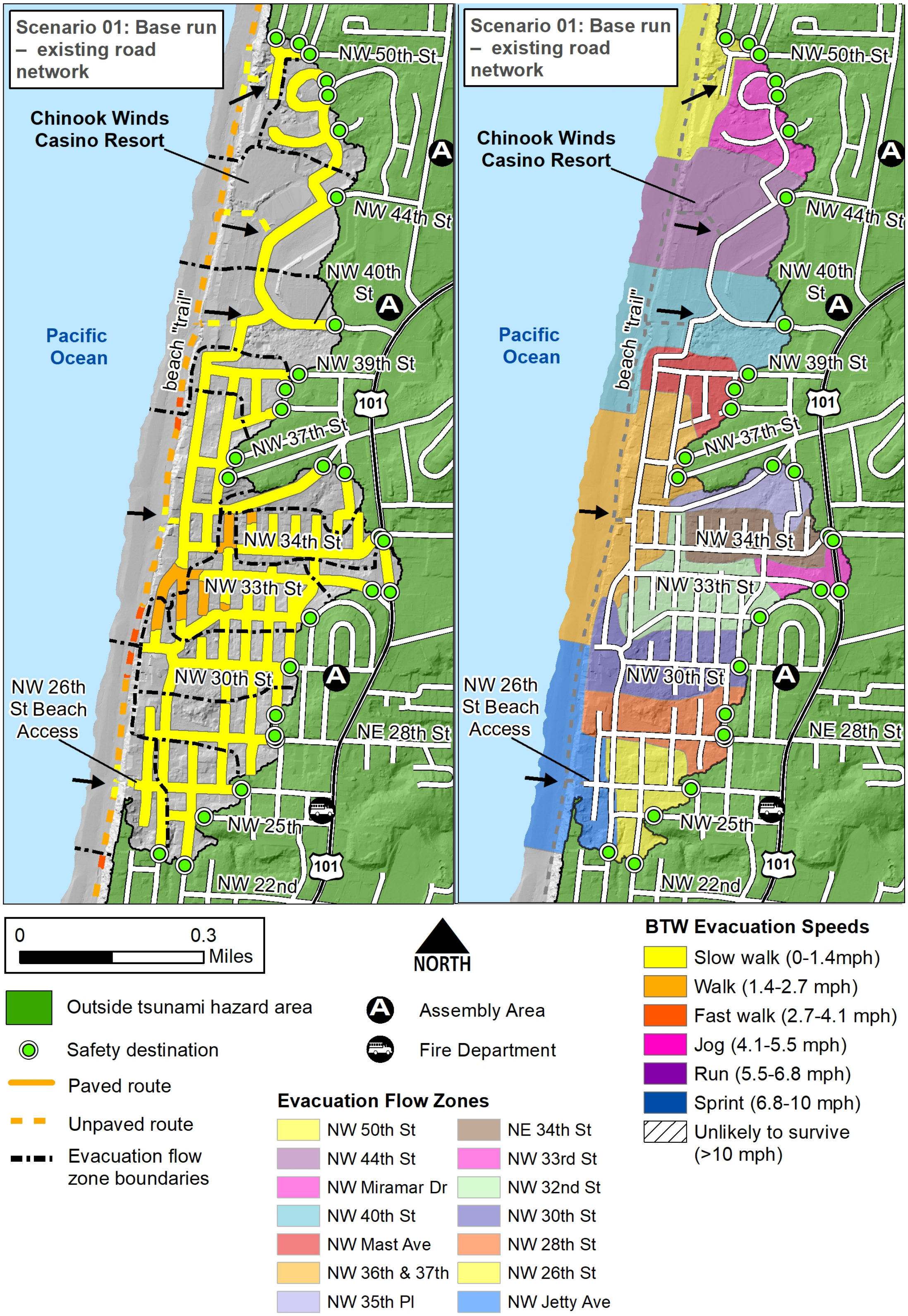
**Figure 3-4. Beat the Wave modeling in Roads End for the base scenario depicting the existing road and trail network. (left) Colors on top of the road network reflect minimum BTW walking speeds. Black dashed lines define evacuation flow zone boundaries. (right) Evacuation flow zones only shown as colored polygons instead of black dashed lines.**



#### *3.1.1.2 Wecoma*

Despite a slightly larger inundation zone in Wecoma than in Roads End, the prevalence of high ground and the density of streets reaching high ground result in an equally optimistic evacuation landscape. Tsunami wave arrival times are also similar, with the first wave arriving on the beach 20 minutes after the start of earthquake shaking and full inundation within another 5 minutes (**Figure 3-3, right**). **Figure 3-5**, **left** shows that all but a few blocks near the beach can reach safety at a minimum walking speed of ***slow walk*** (2 fps or 1.4 mph). Evacuation flow zones are provided in **Figure 3-5, right**. It remains vitally important that people know which direction to evacuate, regardless of the proximity of high ground. Wrong turns, especially in hilly areas with low visibility, result in longer evacuation routes and the possibility that safety will not be reached in time.

**Figure 3-5. Beat the Wave modeling in Wecoma for base scenario. (left) Minimum BTW walking speeds (colors on top of road network) with evacuation flow zone boundaries (black dashed lines) and (right) evacuation flow zones alone.**



#### *3.1.1.3 Oceanlake*

The majority of Oceanlake is outside of the inundation zone except for NW Harbor Avenue on the open coast and the area around D River and Devils Lake, notably NW Inlet Avenue, NE 6th Drive, and Devil's Lake State Rec Area (including a campground). The D River Wayside will be discussed in the next section. Liquefaction susceptibility is moderate to high in this area; therefore we will discuss a second scenario for this neighborhood. The Highway 101 bridge over D River is assumed to fail after the earthquake and is therefore shown to be unavailable for evacuation in these results. Because there is high ground on both sides of this bridge, it does not prove to be necessary for survival and its removal does not affect minimum walking speeds. In other words, those north of D River can find nearby high ground to the north and those south of D River can find nearby high ground to the south; no one needs to cross D River to survive.

The tsunami arrives on the beach in 20 minutes, reaches NW Harbor Ave in ~23 minutes and the campground ~24 after the start of earthquake shaking (**Figure 3-6, top**). **Figure 3-7, top** shows that BTW minimum walking speeds for this area under existing road conditions are ***slow walk***. The additional evacuation difficulty due to potential liquefaction results in slightly higher walking speeds (predominantly ***walk***, 4 fps or 2.7 mph) for the area immediately adjacent to D River and the campground (**Figure 3-7, bottom**). Evacuation flow zones for the base scenario are provided in **Figure 3-6, bottom.**

Despite the fact that most will be able to survive by maintaining a 4 fps walking pace, this area has a slightly more complicated road network that will require a better understanding about which way to evacuate. This is very important for campground visitors who may not know the area well. Clear and well-placed signage is the key to successful evacuation in this neighborhood.

**Figure 3-6. (top) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Oceanlake. (bottom) Evacuation flow zones (base scenario) for Oceanlake.**

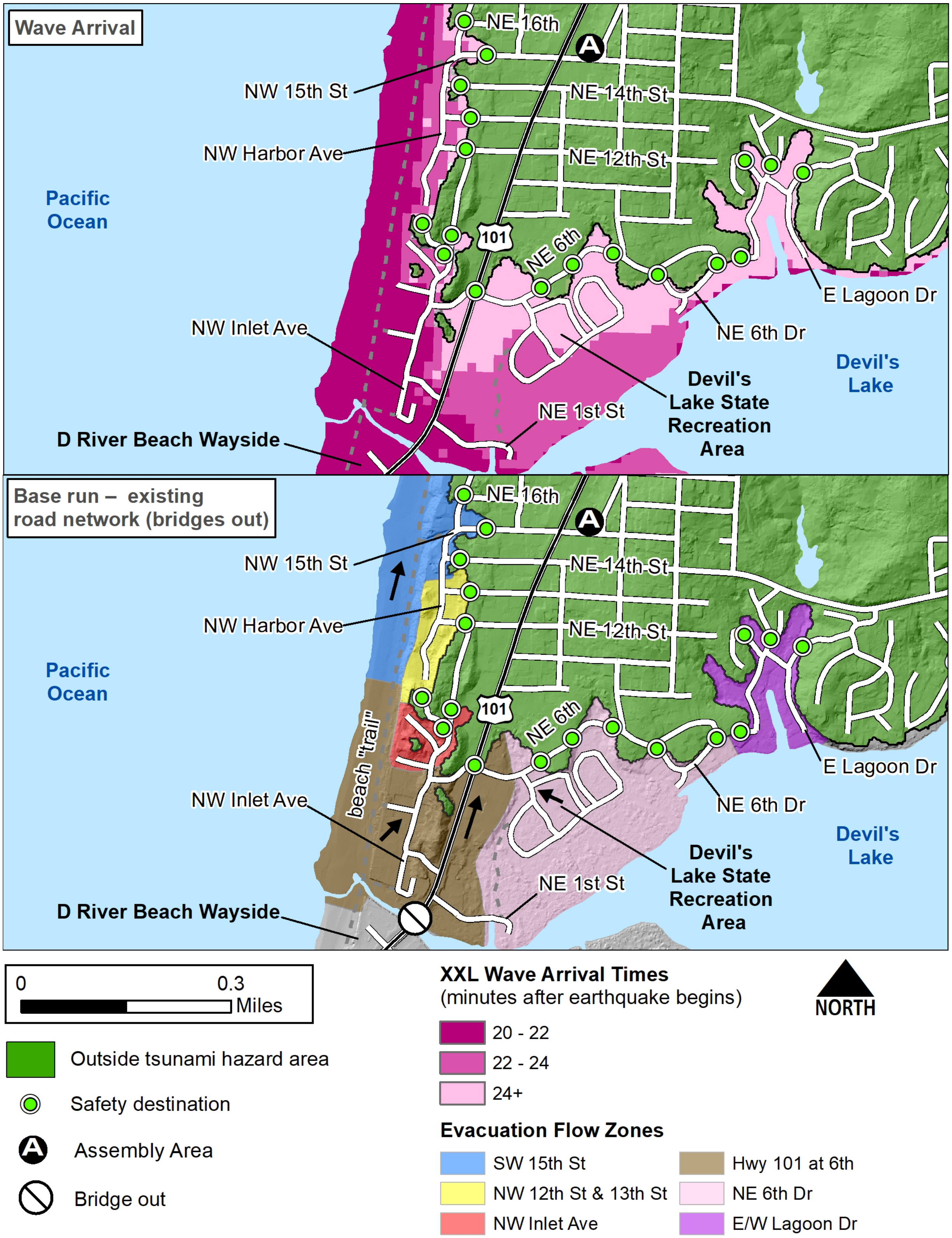
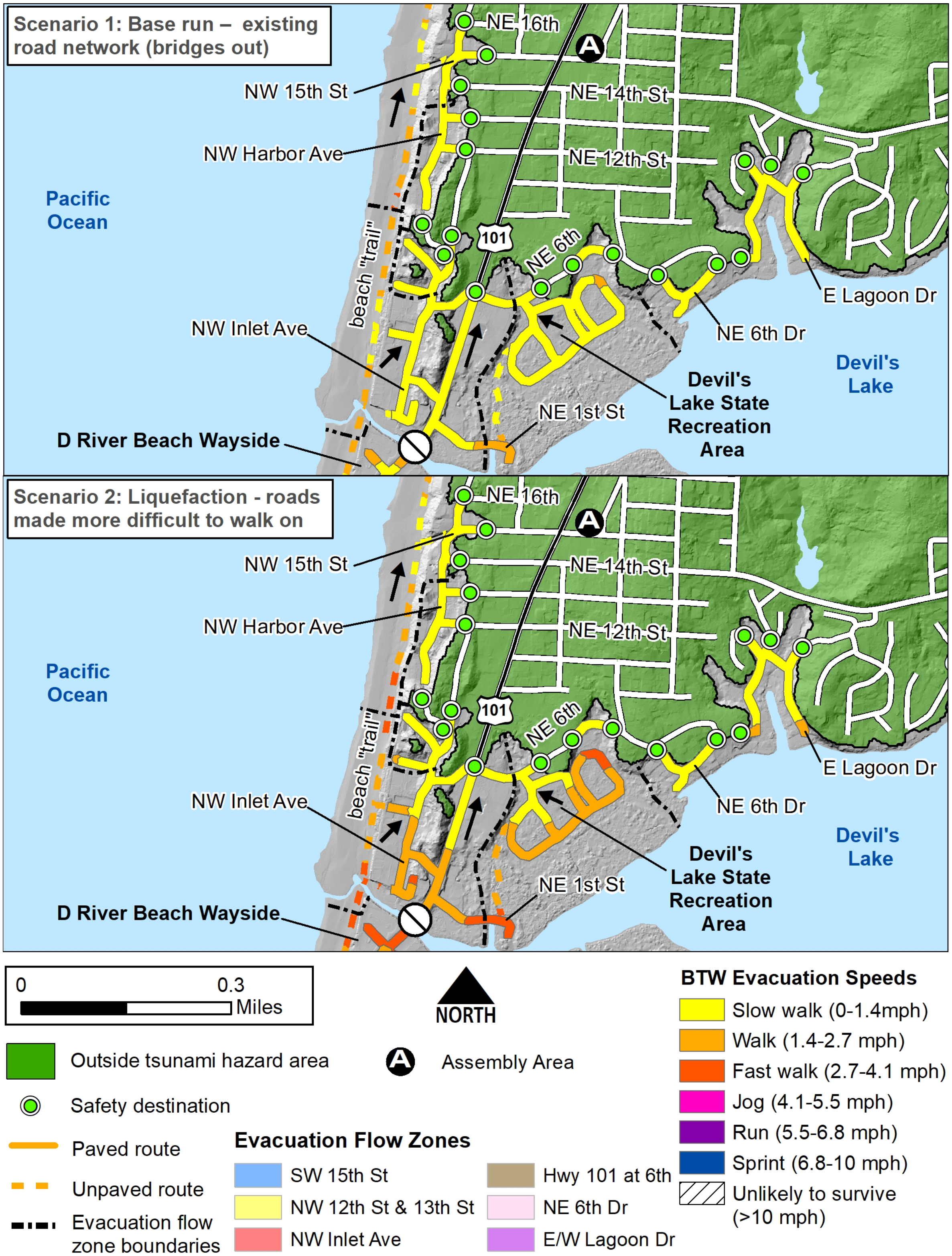


**Figure 3-7. Beat the Wave modeling in Oceanlake for (top) base scenario and (bottom) with liquefaction. Evacuation flow zone boundaries are shown with black dashed lines. Highway 101 bridge over D River is assumed to be impassable.**



#### *3.1.1.4 Delake*

The south side of D River has very little developed land within the inundation zone. However, streets inside the inundation zone are susceptible to liquefaction and also have slightly less straightforward evacuation routes. The TND Fire District Station 2 is also just inside the tsunami zone. As explained in the Oceanlake section, we assume the Highway 101 bridge over D River will not be available for evacuation and our modeling reflects this. The highest density of people will likely be at the D River Wayside, which is a popular beach access parking lot. SE 1st Street and SE 3rd Street are also significantly impacted. The tsunami will reach the Wayside in ~20 minutes and will have fully inundated the area by 25 minutes (**Figure 3-8, top**).

Under current road conditions, everyone in this area can evacuate at a ***slow walk*** except those near the D River Wayside and SE 1st St. Those evacuees must travel at a ***walk*** (4 fps or 2.7 mph) (**Figure 3-9, top**). Evacuation flow zones for the base scenario are presented in **Figure 3-8, bottom**. When liquefaction is introduced, speed in much of the affected area increases to ***walk***; speed in the Wayside area increases to ***fast walk*** and in SE 1st Street increases to ***jog*** (**Figure 3-9, bottom**). Although our modeling confines evacuation routes to streets and roads, individuals should consider alternative routes to their nearest high ground, which may not always involve roads.

**Figure 3-8. (top) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Delake. (bottom) Evacuation flow zones (base scenario) for Delake.**

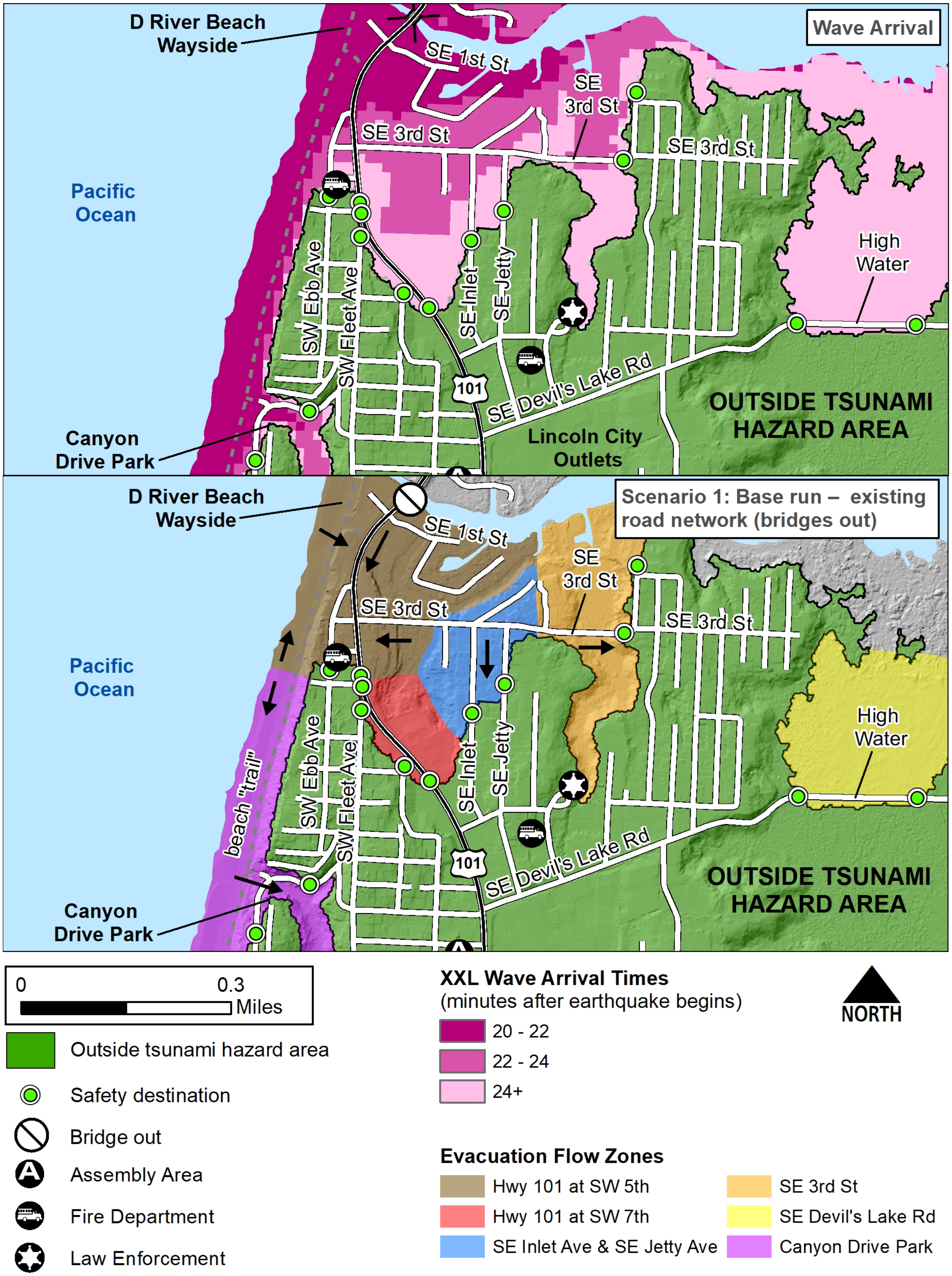
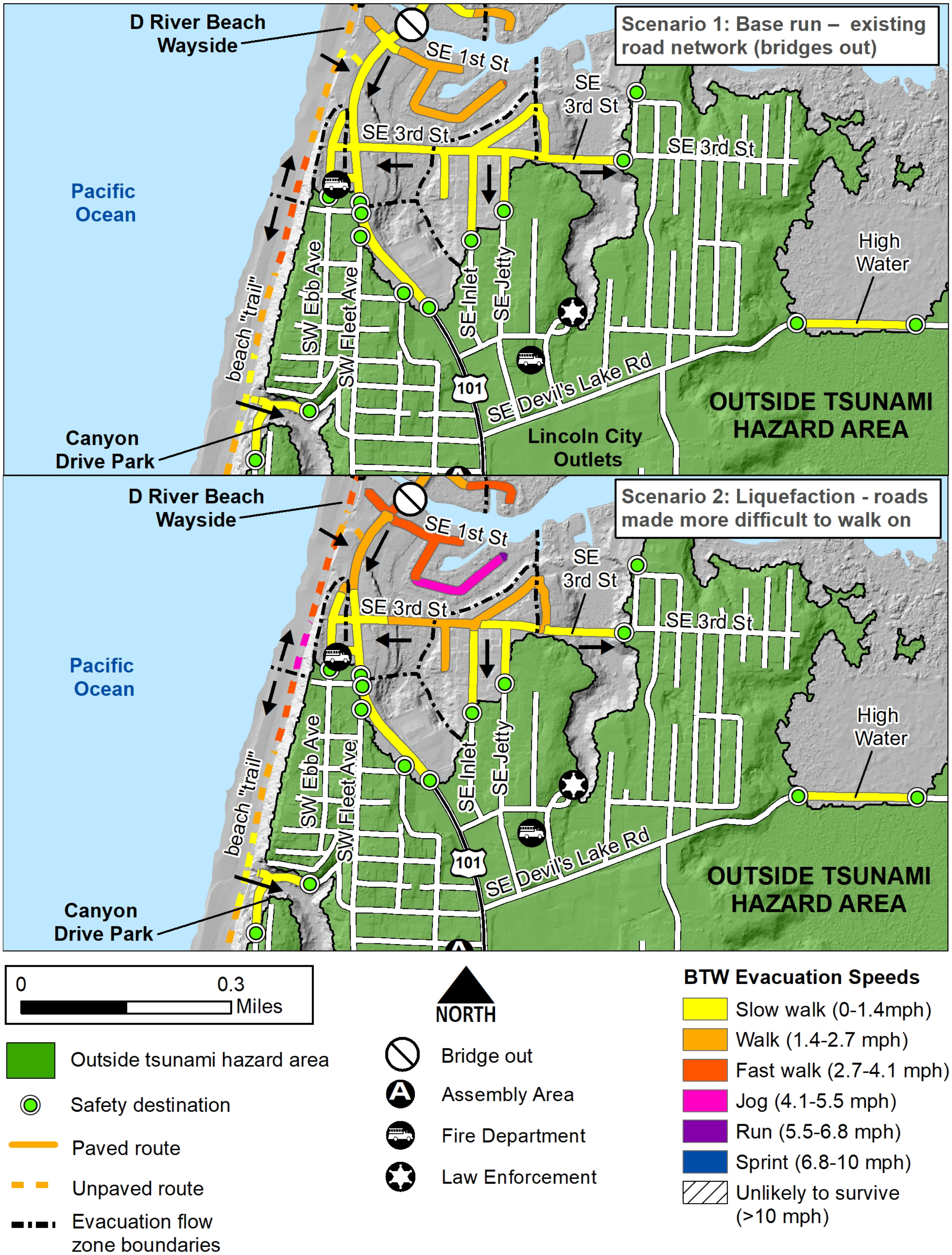


**Figure 3-9. Beat the Wave modeling in Delake for (top) base scenario and (bottom) with liquefaction. Evacuation flow zone boundaries are shown with black dashed lines. Highway 101 bridge over D River is assumed to be impassable.**



#### *3.1.1.5 Nelscott and Taft*

Like Wecoma, Nelscott and Taft have relatively significant amounts of inundation but a high density of roads leaving the inundation zone. Taft has the added complication of liquefaction, which will present difficulties for the area immediately adjacent to Schooner Creek (SE 51st St). Liquefaction was not modeled in Nelscott due to low susceptibility. The Highway 101 bridge over Schooner Creek is assumed to fail during the earthquake and was not included in our BTW modeling.

As elsewhere, the first tsunami wave arrives in 20 minutes and inundation is complete within 5 minutes (**Figure 3-10, left**). The tsunami continues up Schooner Creek just past the Anderson Creek bridge (not shown), arriving there ~35 minutes after the earthquake shaking begins. **Figure 3-11, left** demonstrates that evacuees from both neighborhoods can reach high ground at a ***slow walk***; however, **Figure 3-11, right** shows that liquefaction will significantly increase evacuation difficulty for those along Schooner Creek, with speeds along some streets increasing to a ***fast walk*** and ***jog*** (8 fps or 5.5 mph). SE 51st Street will also potentially experience lateral spreading, a phenomenon where roads adjacent to waterways slump into the waterway during earthquake shaking. As discussed in section 2.2, lateral spreading is too site-specific to be effectively modeled by BTW. We note it here it to encourage additional investigation. Evacuation flow zones for the base scenario are presented in **Figure 3-10, right** to assist with evacuation planning.

**Figure 3-10. (left) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Nelscott and Taft. (right) Evacuation flow zones (base scenario) for Nelscott and Taft.**

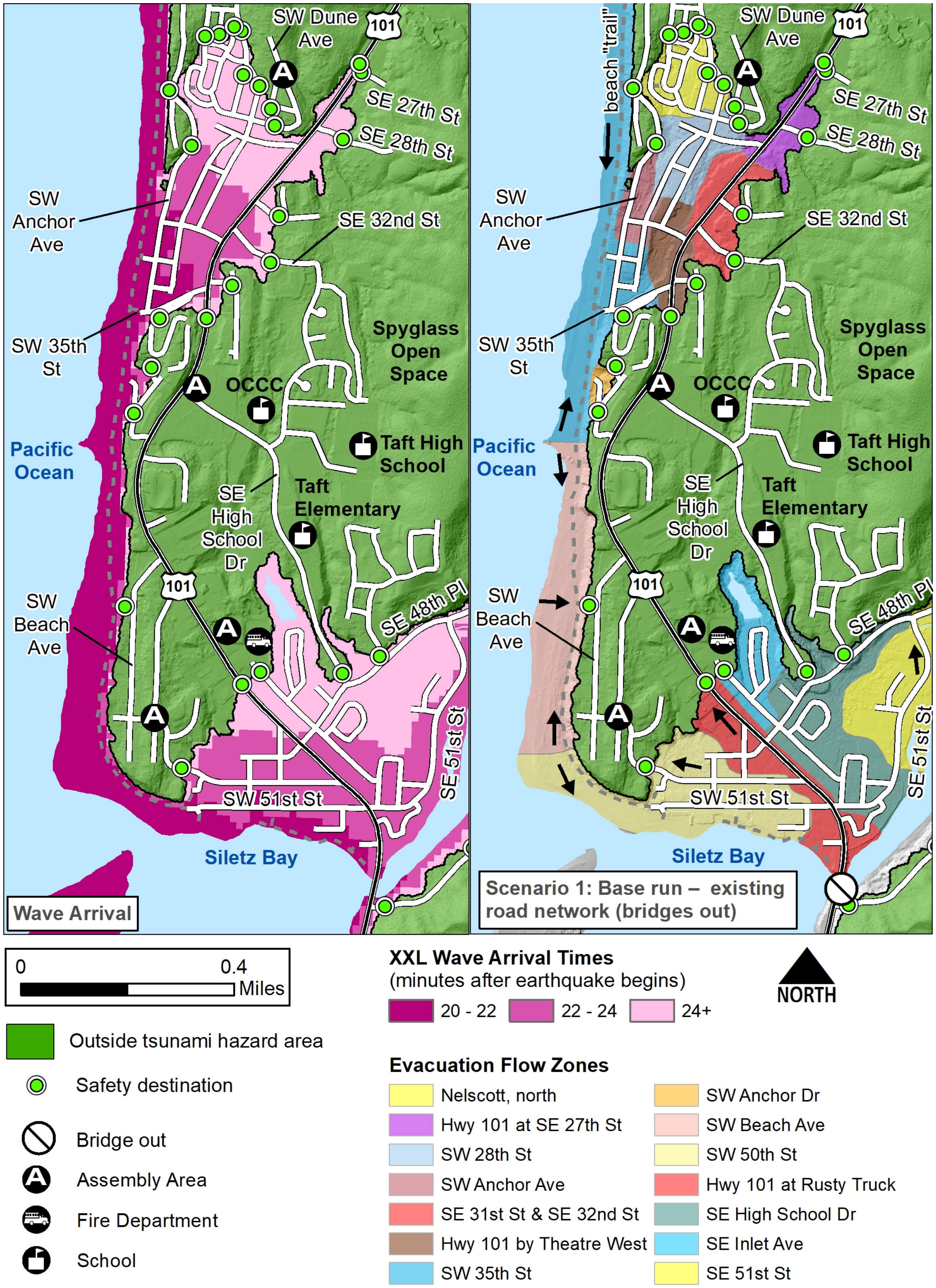
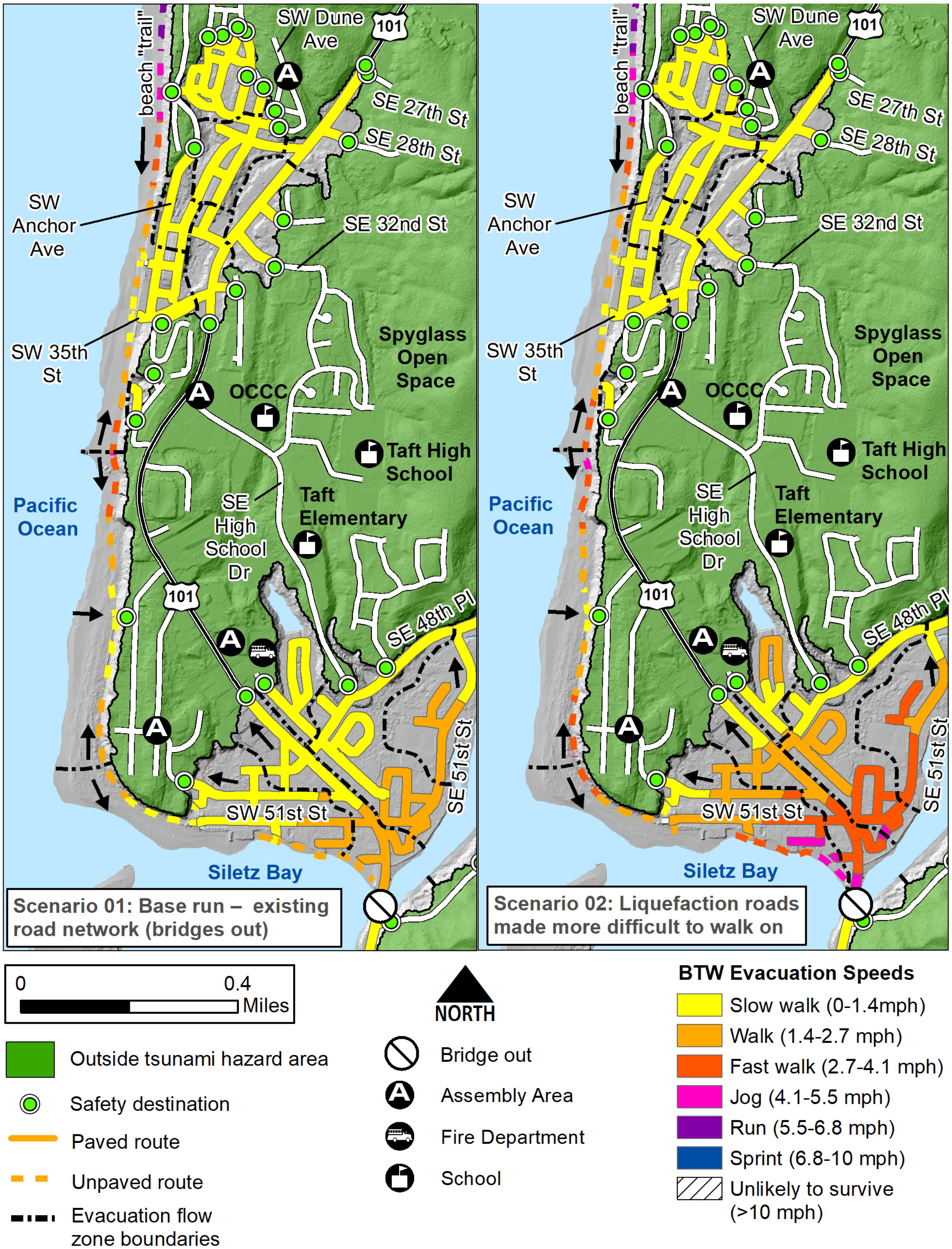


**Figure 3-11. Beat the Wave modeling in Nelscott and Taft for (left) base scenario and (right) with liquefaction (changes results in Taft only). Evacuation flow zone boundaries are shown with black dashed lines. Highway 101 bridge over Schooner Creek is assumed to be impassable.**



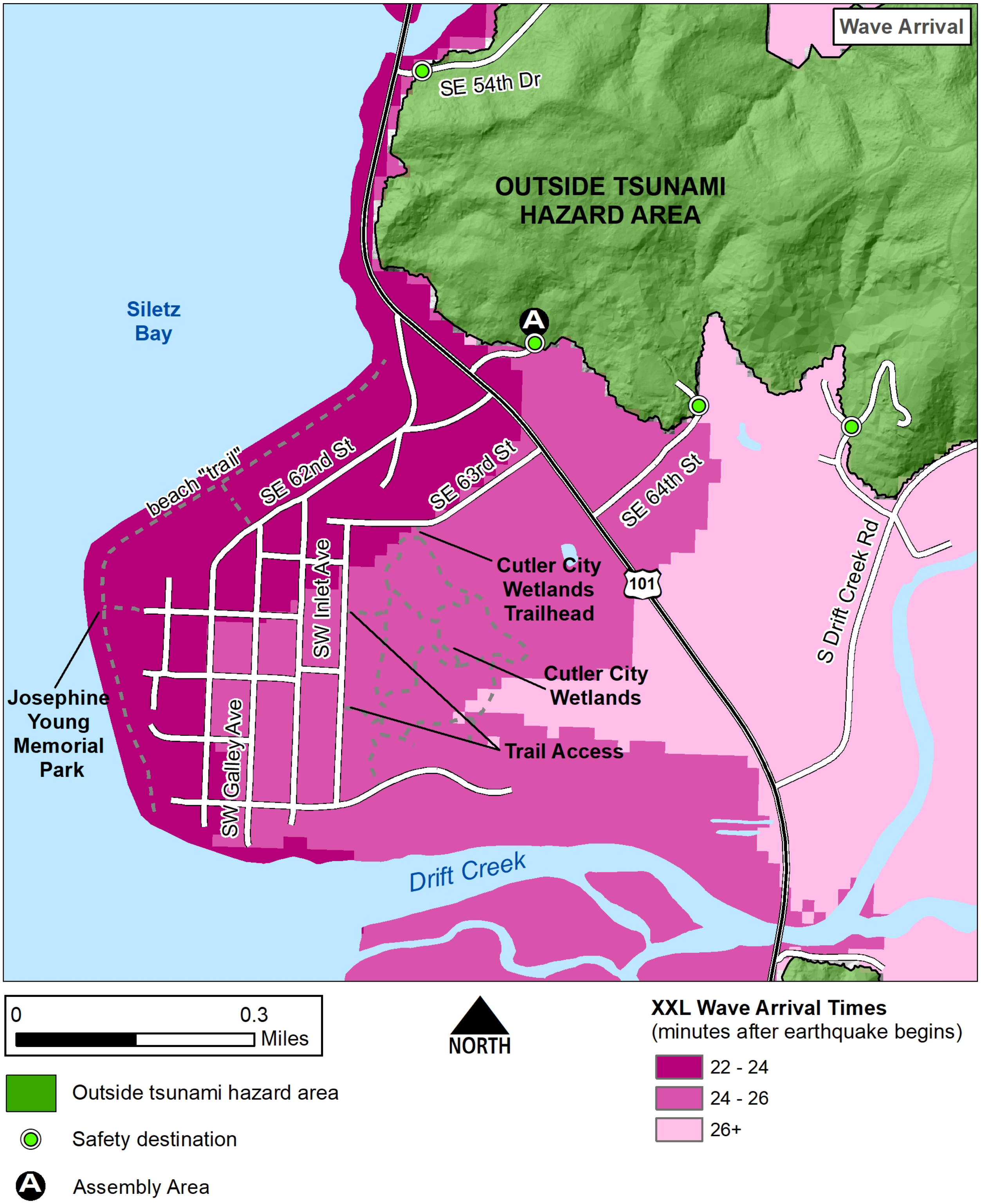
#### *3.1.1.6 Cutler City*

Cutler City possesses a unique evacuation challenge due to its geography. It resides on a low-lying peninsula at the edge of Siletz Bay. At ~12 ft above sea level, the neighborhood is completely within the inundation zone. Safety can be found on the other side of Highway 101. Reaching safety requires exiting the neighborhood via one of two access roads (SE 62nd St or SE 63rd St) and heading ~100 feet up a private driveway off Highway 101 near SE 62nd St. The city had an agreement with a former property owner that a site on their property be designated as an assembly area in the event of an earthquake and tsunami. This agreement allowed for occasional evacuation drills, a vital exercise to ensure residents are prepared. It is our hope that a similar agreement can be made with current and future property owners due to its extreme importance to life safety for Cutler City. This destination is marked as an Assembly Area on figures in this report as well as in published evacuation brochures.

The tsunami arrives a few minutes later here than other Lincoln City neighborhoods because the wave must travel across Siletz Bay before reaching Cutler City. The first wave arrives in ~22 minutes and inundates the neighborhood almost immediately (**Figure 3-12**).

Cutler City has high liquefaction susceptibility due to its proximity to the bay. In addition to a liquefaction scenario, two hypothetical mitigation options are considered here. Subsidence during the earthquake may result in a lowering of the ground surface by as much as 5.5 feet. This may result in additional water on the roadways during evacuation, further challenging evacuation, but this potential challenge was not modeled in our study.

**Figure 3-12. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Cutler City.**



#### *3.1.1.6.1 Existing road network and liquefaction*

A base run that assumes all roads in Cutler City are available and easy to walk on yields BTW minimum walking speeds of ***walk*** and ***fast walk*** (**Figure 3-13, top**). Under these ideal conditions, residents at the south end of Cutler City (SW 69th St) must maintain a ***fast walk*** (6 fps or 4.1 mph) for ~0.7 miles. However, a more realistic picture of evacuation in Cutler City incorporates the effects of liquefaction.

High liquefaction susceptibility results in a dramatic increase in minimum walking speeds necessary to reach high ground before the tsunami arrives (**Figure 3-13, bottom**). The northern third of the neighborhood increases from ***walk*** to ***fast walk***; the central region increases from ***walk***/***fast walk*** to ***jog***, and at the southern end, which is the farthest from safety, speeds increase from ***fast walk*** to ***run*** with a small extent of ***sprint***. Those on SW 69th St must sustain a ***run*** (10 fps or 6.8 mph) for 0.7 miles if soft sand, mud, and standing water are present on all roads.

#### *3.1.1.6.2 Hypothetical vertical evacuation structure*

The high walking speeds required in a liquefaction scenario prompted us to consider the effect of a hypothetical vertical evacuation structure in Cutler City. The best location provides refuge to as much of the neighborhood as possible; therefore, we chose the current location of the Pacific Baptist Church because it is centrally located and on the main road (**Figure 3-14, top**). Liquefaction was included in this run to provide a more realistic representation of how the structure will improve evacuation potential. As expected, the presence of a centrally located life-saving structure dramatically reduces minimum walking speeds necessary to reach safety ahead of the wave, down to ***slow walk*** and ***walk*** (4 fps or 2.7 mph).

This analysis presupposes that any vertical evacuation structure has adequate capacity for the population served and is designed and constructed to remain intact and accessible after the earthquake shaking while also resisting tsunami forces and scour. The significant height of the structure, potential large footprint, and large cost are likely to be deterrents. Costs versus benefits must be carefully evaluated, including the possibility of designing a structure built to withstand a smaller tsunami, such as that modeled in the L1 scenario, characterized by significantly shallower flow depths.

#### *3.1.1.6.3 Hypothetical road hardening*

Another hypothetical option would be to ensure that a single arterial route within the neighborhood remains passable by engineering the road to resist liquefaction and/or other earthquake-induced road impediments. **Figure 3-14, bottom** illustrates the evacuation improvements this option would bring to the neighborhood. Because everyone still must travel to the assembly area on the other side of Highway 101, it is not as effective as a vertical evacuation structure, but it does reduce walking speeds from the liquefaction scenario. Speed for much of the neighborhood is ***fast walk***. As with a vertical evacuation structure, a site-specific analysis would be necessary to evaluate the viability of this option.

**Figure 3-13. Beat the Wave modeling in Cutler City for (top) base scenario and (bottom) with liquefaction. Evacuation flow zone boundaries are shown with black dashed lines. Highway 101 bridges over Schooner Creek and Drift Creek are assumed to be impassable.**

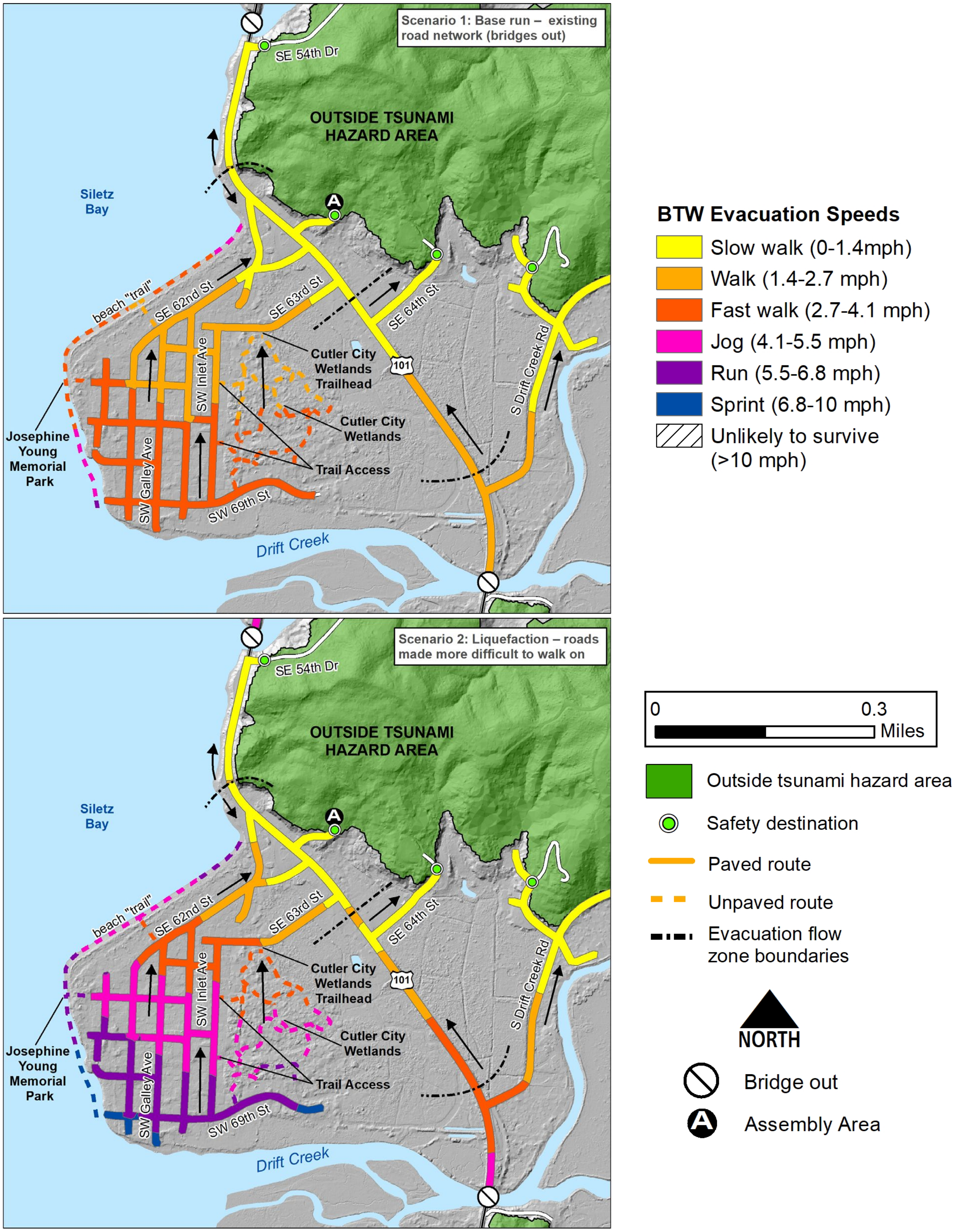
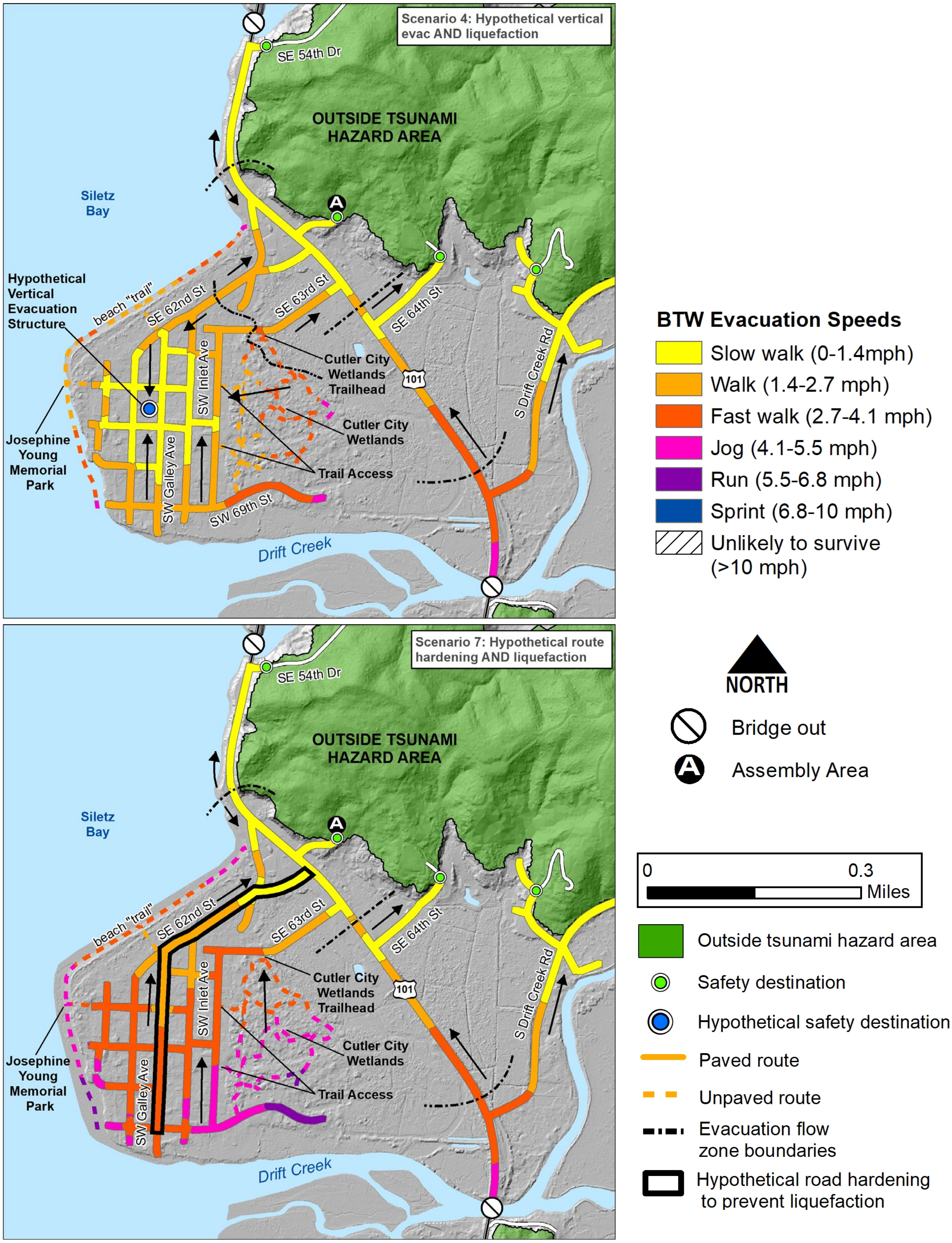


**Figure 3-14. Beat the Wave modeling in Cutler City for (top) hypothetical vertical evacuation structure and (bottom) hypothetical earthquake-hardened road. Evacuation flow zone boundaries are shown with black dashed lines. Highway 101 bridges over Schooner Creek and Drift Creek assumed to be impassable.**



### 3.1.2 Siletz Bay, Gleneden Beach, and Lincoln Beach

This section of Lincoln County can be separated into two distinct geographic regions (**Figure 3-15**). Siletz Spit, Salishan, and Siletz Keys are low-lying communities adjacent to Siletz Bay that will experience significant tsunami inundation and are highly susceptible to liquefaction. Gleneden Beach, Lincoln Beach, and Fogarty Creek are bluff-backed open coast areas characterized by limited inundation and low liquefaction susceptibility.

A regional view of tsunami wave arrival is shown in **Figure 3-16**. Detailed wave arrival figures are provided for all figure extents except Siletz Spit and Siletz Keys, where the regional map provides enough detail. The earliest wave arrivals are along the open coast: the tsunami reaches the beach ~20 minutes after the start of earthquake shaking. Within 28 minutes, much of the study area is expected to be inundated. Tsunami wave arrival time data are found in the Lincoln_County_Tsunami_Evacuation_Modeling geodatabase, TsunamiWaveArrival_XXL1 dataset.

Overall, Gleneden Beach and Lincoln Beach have short distances to safety and multiple safety destinations, resulting in low minimum walking speeds. Siletz Spit and Siletz Keys, however, have longer distances to safety and fewer options, which will be discussed in detail below. Walking speeds on the roads and trails as well as evacuation flow zone data for the base scenario are found in the Lincoln_County_Tsunami_Evacuation_Modeling geodatabase, XXL1_BridgesOut feature dataset.

**Figure 3-15. Siletz Spit, Siletz Keys, Salishan, Gleneden Beach, Lincoln Beach, and Fogarty Creek area map showing figure extents.**

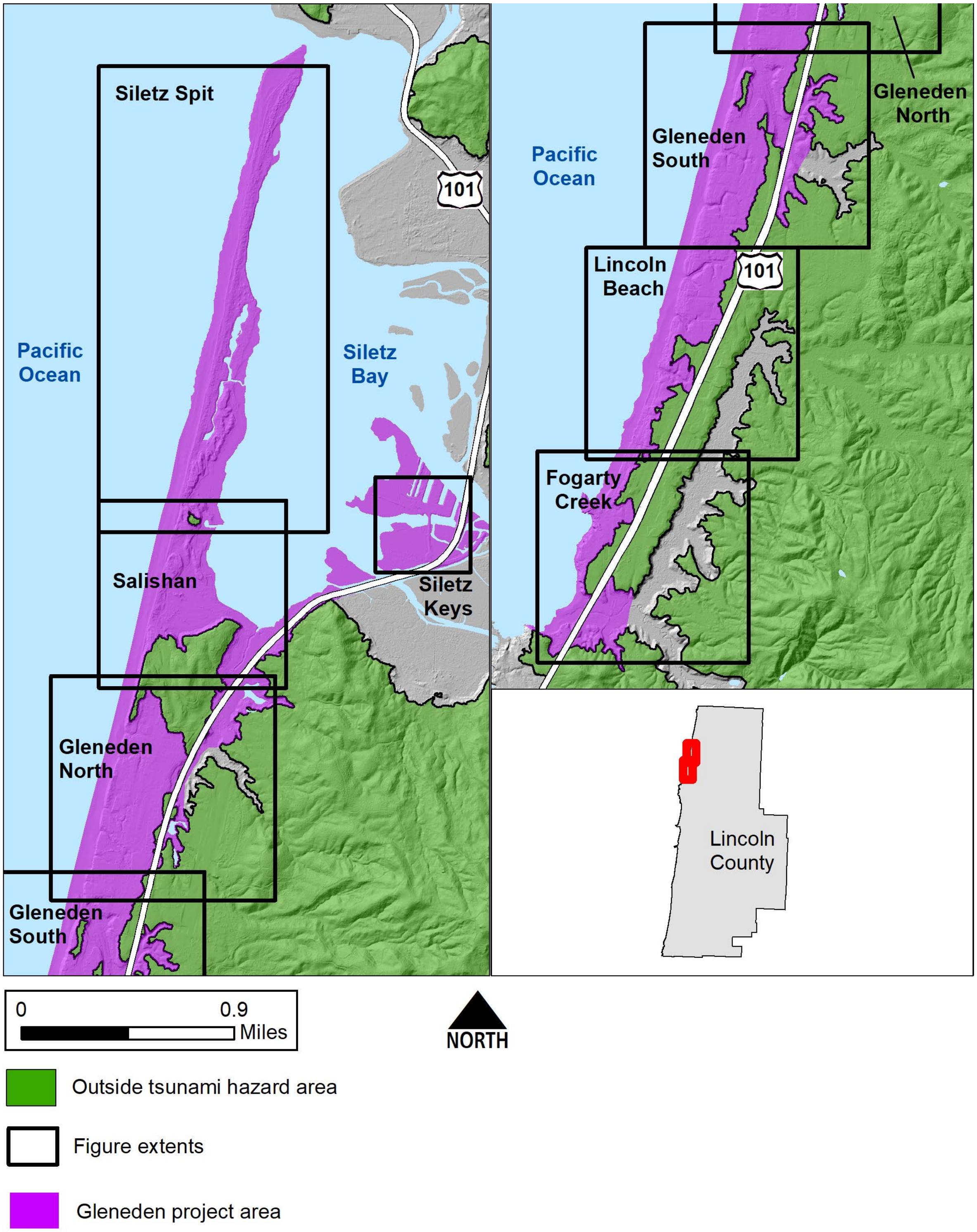
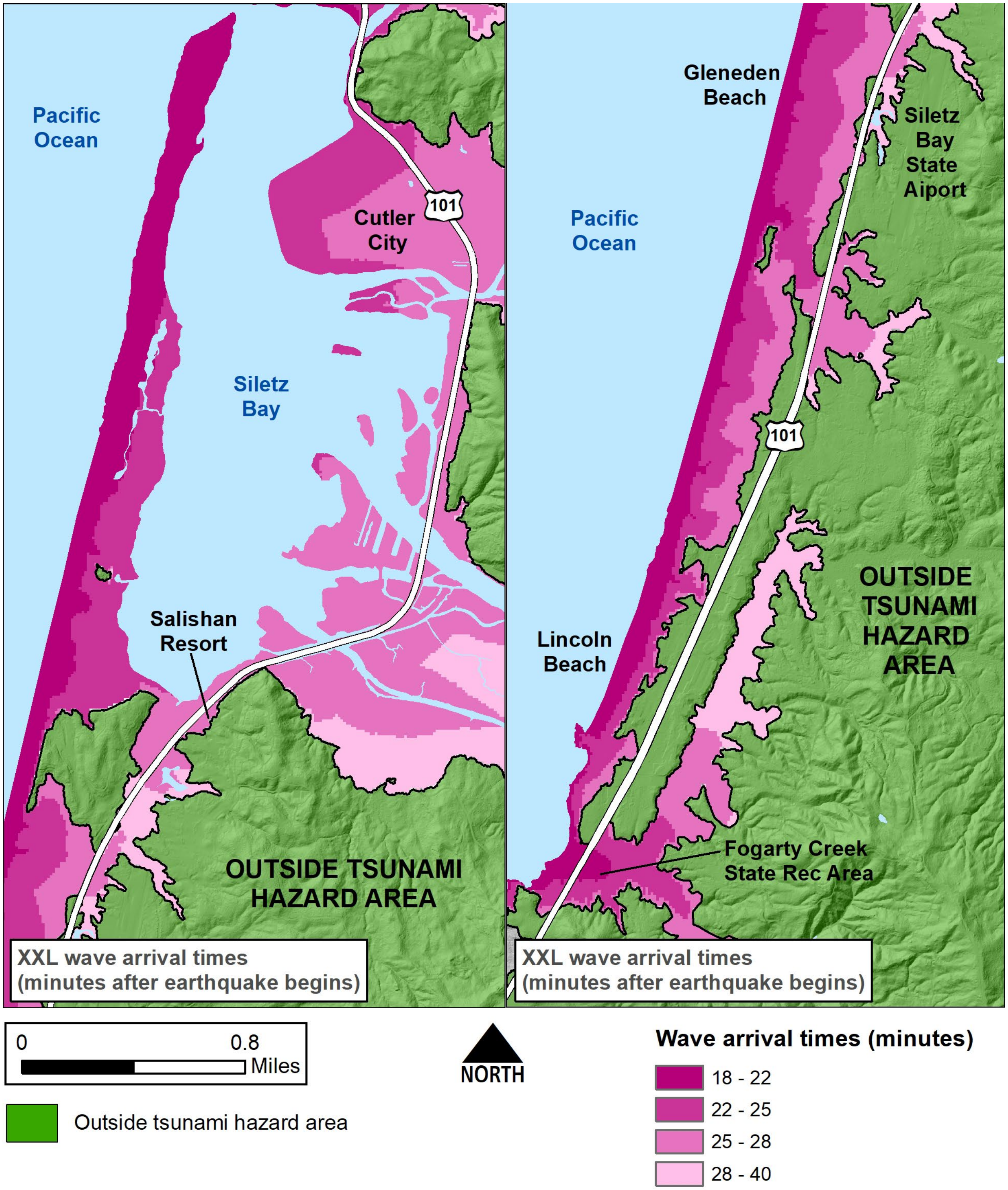


**Figure 3-16. Illustration of tsunami wave arrivals at Siletz Bay, Gleneden Beach, Lincoln Beach, and Fogarty Creek after XXL Cascadia subduction zone earthquake. Note the variable wave arrival time bin values.**



#### *3.1.2.1 Siletz Spit*

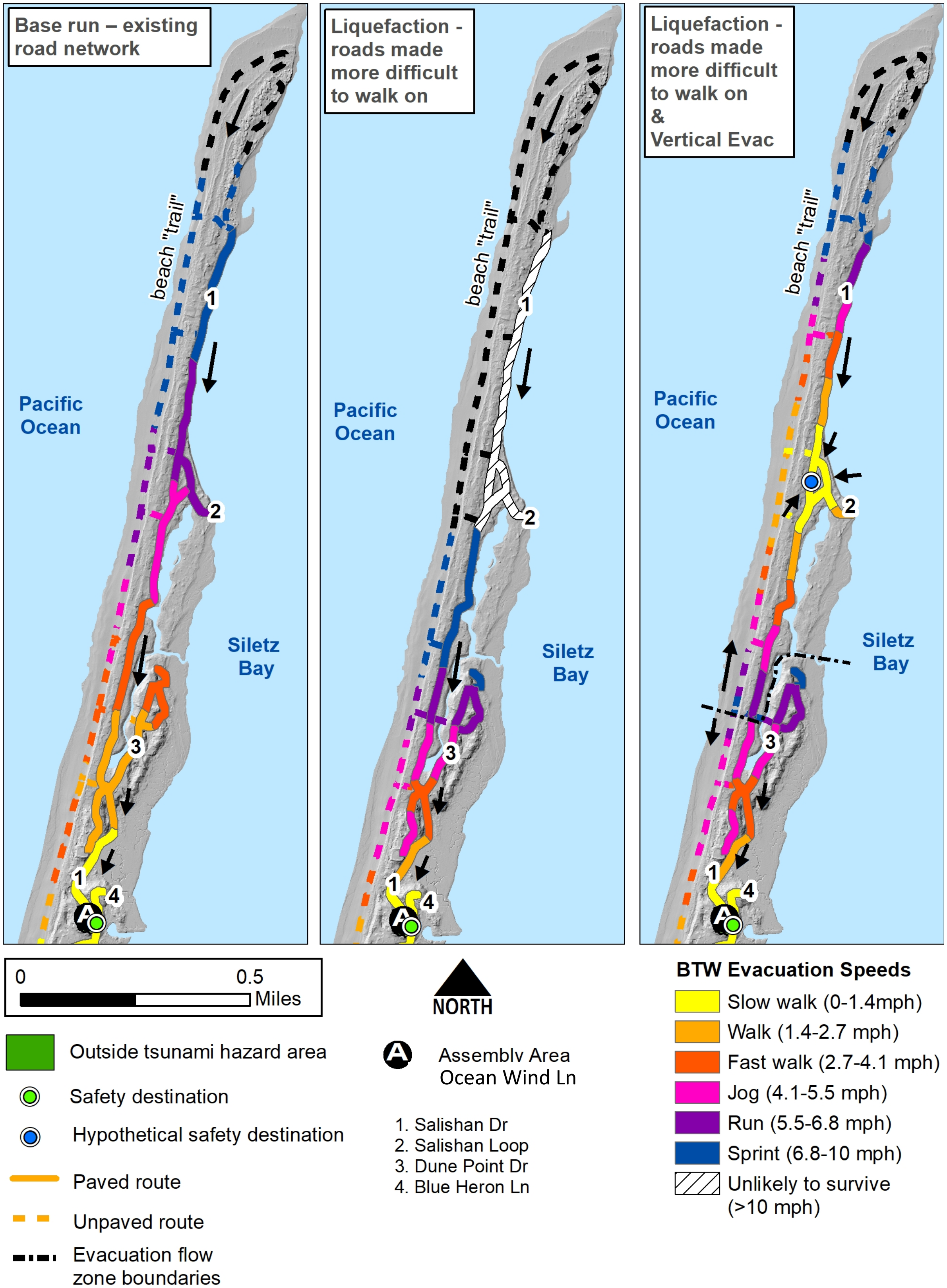
Siletz Spit extends ~2 miles from the mouth of Siletz Bay in the north to the larger Salishan community in the hills to the south. A single road, Salishan Dr, connects the community on the spit with Salishan. High ground for the spit is on Ocean Wind Ln, also a designated assembly area. The tsunami arrives and overtops spit in ~20–22 minutes (**Figure 3-16**).

Overall, evacuation results are similar to results for other remote coastal areas, namely that much faster travel speeds are needed to reach safety, safety destinations are limited, and land cover conditions (i.e., loose sand and wetlands) can make evacuation difficult. The lack of high ground on the spit means there are not a lot of options for mitigation aside from constructing a vertical evacuation structure, which is considered below along with the added challenge of liquefaction.

Minimum walking speeds on Salishan Drive are as low as ***walk*** for the first ~0.5 miles and reach a maximum of ***sprint*** (15 fps or 10 mph) at the north end for the base BTW scenario (**Figure 3-17, left**). Liquefaction increases walking speeds for the entire area, with those north of Salishan Loop ***unlikely to survive*** (>15 fps or >10 mph) (**Figure 3-17, middle**). These results prompted us to consider the improvements that could be made by the construction of a vertical evacuation structure. **Figure 3-17, right** present minimum walking speeds for this scenario, which also includes liquefaction to better reflect expected conditions.

Although there is no safe ground on the spit in the case of an XXL tsunami, there are a few hills around Dune Point Drive that are high enough to be considered safe in a Large (L1) tsunami scenario. We did not model this scenario because when following the road network, this does not significantly reduce distances to safety for those at the far end of the spit. A shortcut across South Lagoon (the body of water immediately north of Dune Point Dr; not labeled in **Figure 3-17**) would likely result in a significant reduction to minimum walking speeds, and we encourage local decision makers to further explore this and other evacuation options. This shortcut would likely need to be an earthquake-resistant footbridge.

**Figure 3-17. Beat the Wave modeling in Cutler City for (left) base scenario, (middle) with liquefaction, and (right) hypothetical vertical evacuation structure. Evacuation flow zone boundaries are shown with black dashed lines.**



#### *3.1.2.2 Siletz Keys*

Siletz Keys is a small low-lying community within Siletz Bay. Evacuees can reach high ground only after crossing a single levee-type road leading back to Highway 101 and then one of two significant bodies of water via bridge. The Millport Slough bridge was rebuilt in 2015 and is expected to survive the shaking from a Cascadia earthquake (Yumei Wang, written communication, 2019). The Siletz River bridge, however, was built in 1973 and is not expected to survive the earthquake. The nearest high ground to the south is at Salishan Lodge, ~1.2 miles away. High ground to the north is ~0.8 miles away along S Wells Drive in Kernville. It will take approximately 26 minutes for the tsunami to arrive (**Figure 3-16**).

Due to the distance from safety, we first present an area map (**Figure 3-18**) showing both evacuation options: north over Siletz River Bridge or south over Millport Slough bridge. **Figure 3-19** presents results for three BTW scenarios. **Figure 3-19, left** demonstrates minimum BTW walking speeds necessary to survive when evacuating south to Salishan Lodge over the Millport Slough bridge. This reflects existing road conditions based on the expected survival of the bridge. About half the neighborhood must maintain a speed of ***jog*** (8 fps or 5.5 mph) and the other half a speed of ***run*** (10 fps or 6.8 mph). There may be opportunities to find high ground closer than Salishan Lodge by climbing the hillside adjacent to Highway 101 or S Immonen Rd, but this was not modeled.

Liquefaction is likely to affect evacuation in Siletz Keys due to that area's low elevation. **Figure 3-19, middle** demonstrates the increased BTW minimum walking speeds that evacuees must maintain all the way to Salishan Lodge: from ***jog*** and ***run*** to ***sprint*** and a small section that is ***unlikely to survive*** (>10 mph).

It is worth considering the evacuation improvements that would be gained from retrofitting the Siletz River bridge. Evacuation distance is reduced by 0.4 miles and minimum walking speeds are reduced from ***jog***/***run*** to ***fast walk/jog*** (**Figure 3-19, right**).

**Figure 3-18. Area map for Siletz Keys showing high ground to the north via Siletz River Bridge and to the south via Millport Slough Bridge. Figure 3-19 presents BTW results for Siletz Keys at the extent shown in red.**

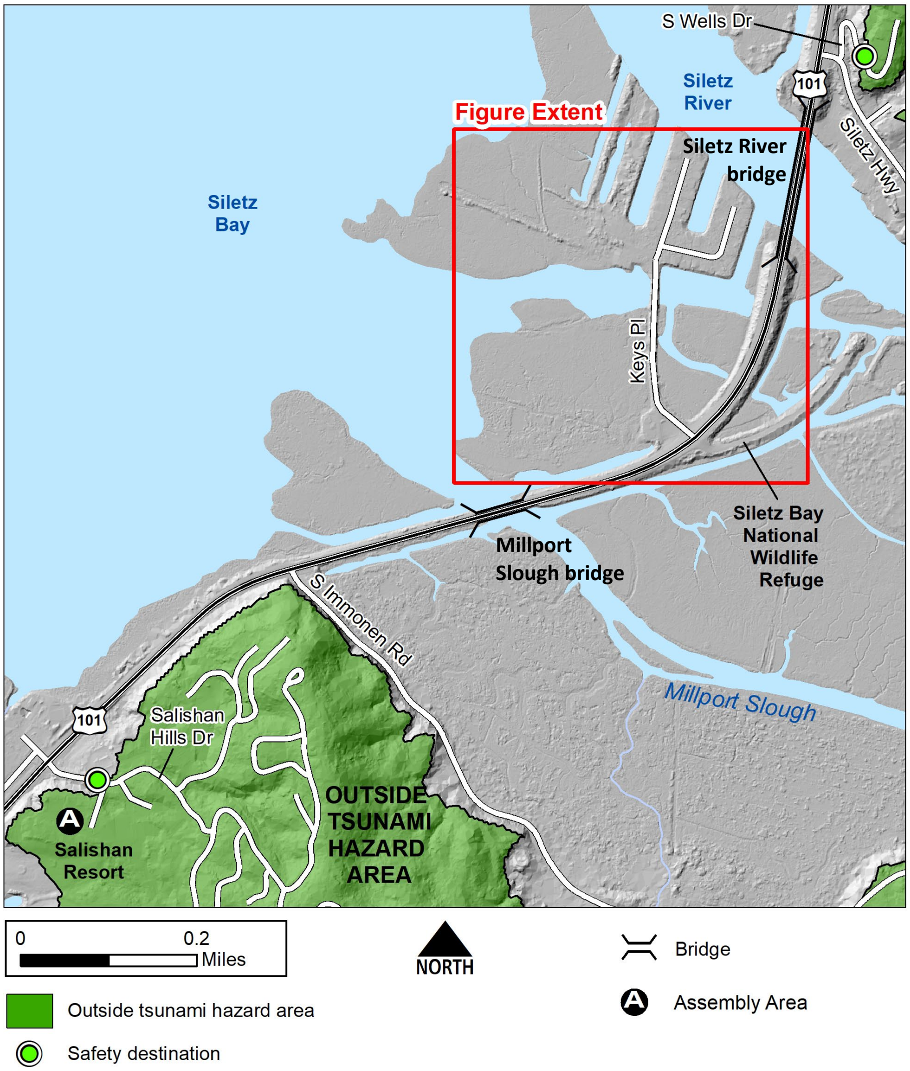
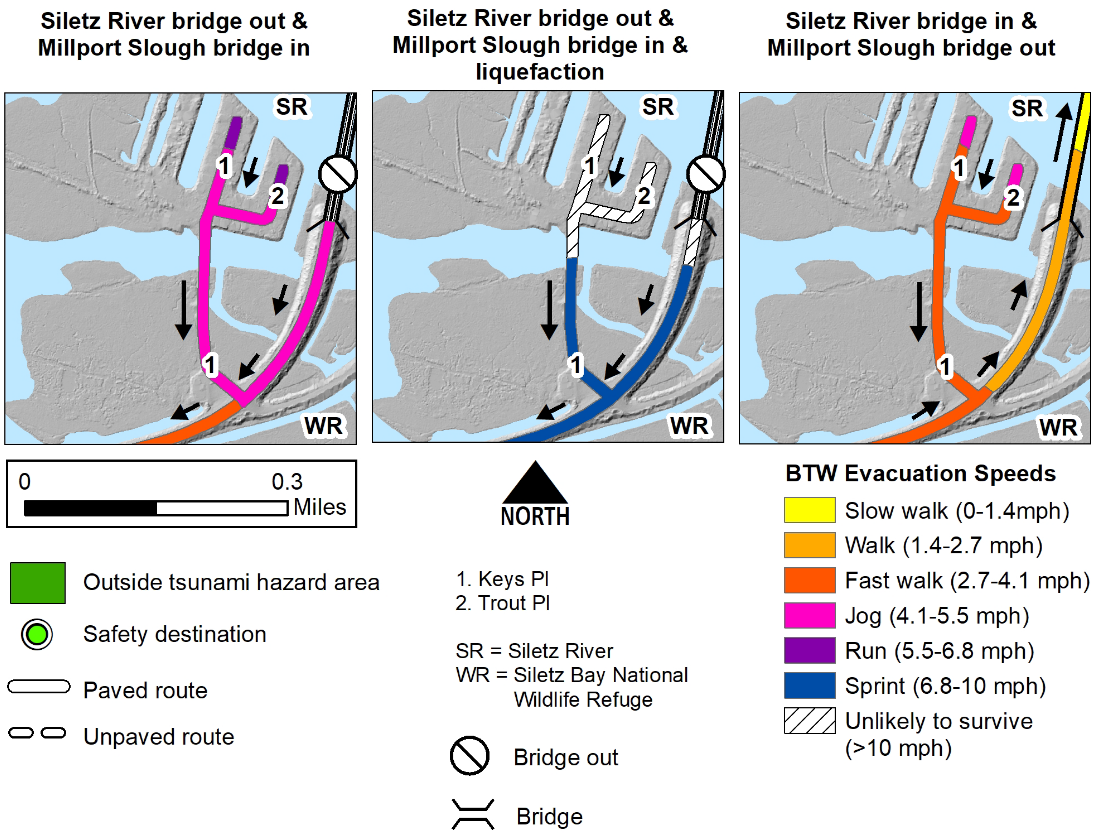


**Figure 3-19. Beat the Wave modeling in Siletz Keys for (left) base scenario assuming Millport Slough bridge survives and Siletz River bridge fails; (middle) with liquefaction; and (right) hypothetical retrofit of Siletz River bridge (no liquefaction).**



### *3.1.2.3 Salishan*

The Salishan area consists of the Salishan Resort spa and golf course and southern end of the gated community of Salishan. There is a significant amount of high ground in this region, resulting in low BTW walking speeds. As always, knowing which direction to travel is important because even when safety is nearby, the route to safety may not be obvious. A particular decision that some people will have to make in this area is whether to head north to the island of high ground by Blue Heron Ln or south on Salishan Dr. The Highway 101 bridge over a pedestrian underpass is assumed to fail during the earthquake, and our modeling prevents passage across that bridge. However, this stretch of Highway 101 is unpopulated and we do not anticipate a high reliance on that bridge during evacuation.

The tsunami arrives on the open coast ~20 minutes after the start of earthquake shaking and reaches Salishan Dr about 2 minutes later (**Figure 3-20**). Highway 101 is expected to be flooded by ~25 minutes.

**Figure 3-21** presents BTW results for the Salishan area assuming the existing road network remains intact and easily passable. The minimum needed evacuation speed is ***walk*** (4 fps or 2.7 mph) (**Figure 3-21, top**). Evacuation flow zones are presented in **Figure 3-21, bottom**. Liquefaction slightly increases walking speeds, introducing ***fast walk*** to the golf course and a small section of Salishan Dr (**Figure 3-22**).

**Figure 3-20. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Salishan.**

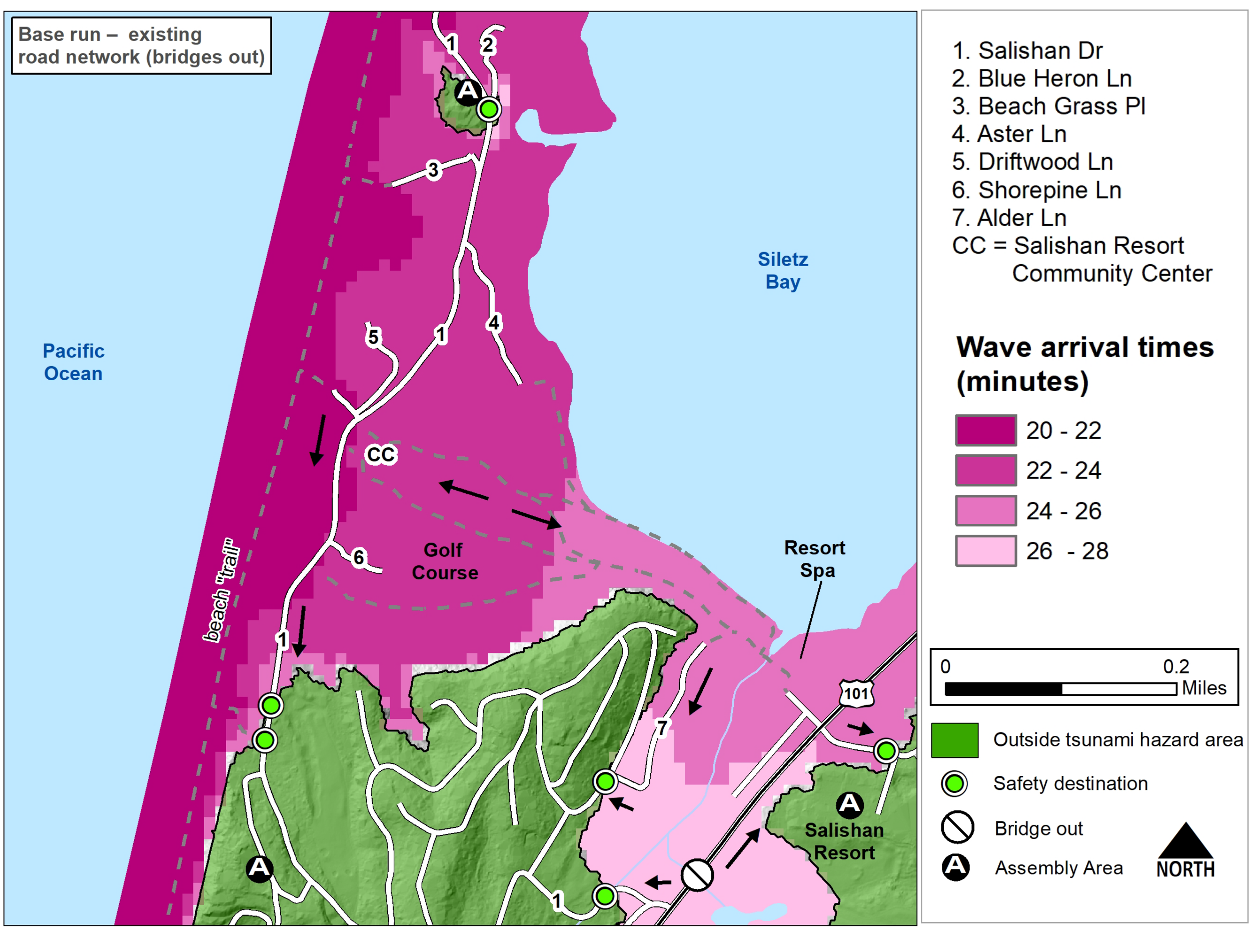


**Figure 3-21. Beat the Wave modeling in Salishan for base scenario. (top) Minimum BTW walking speeds (colors on top of road network) with evacuation flow zone boundaries (black dashed lines) and (bottom) evacuation flow zones alone.**

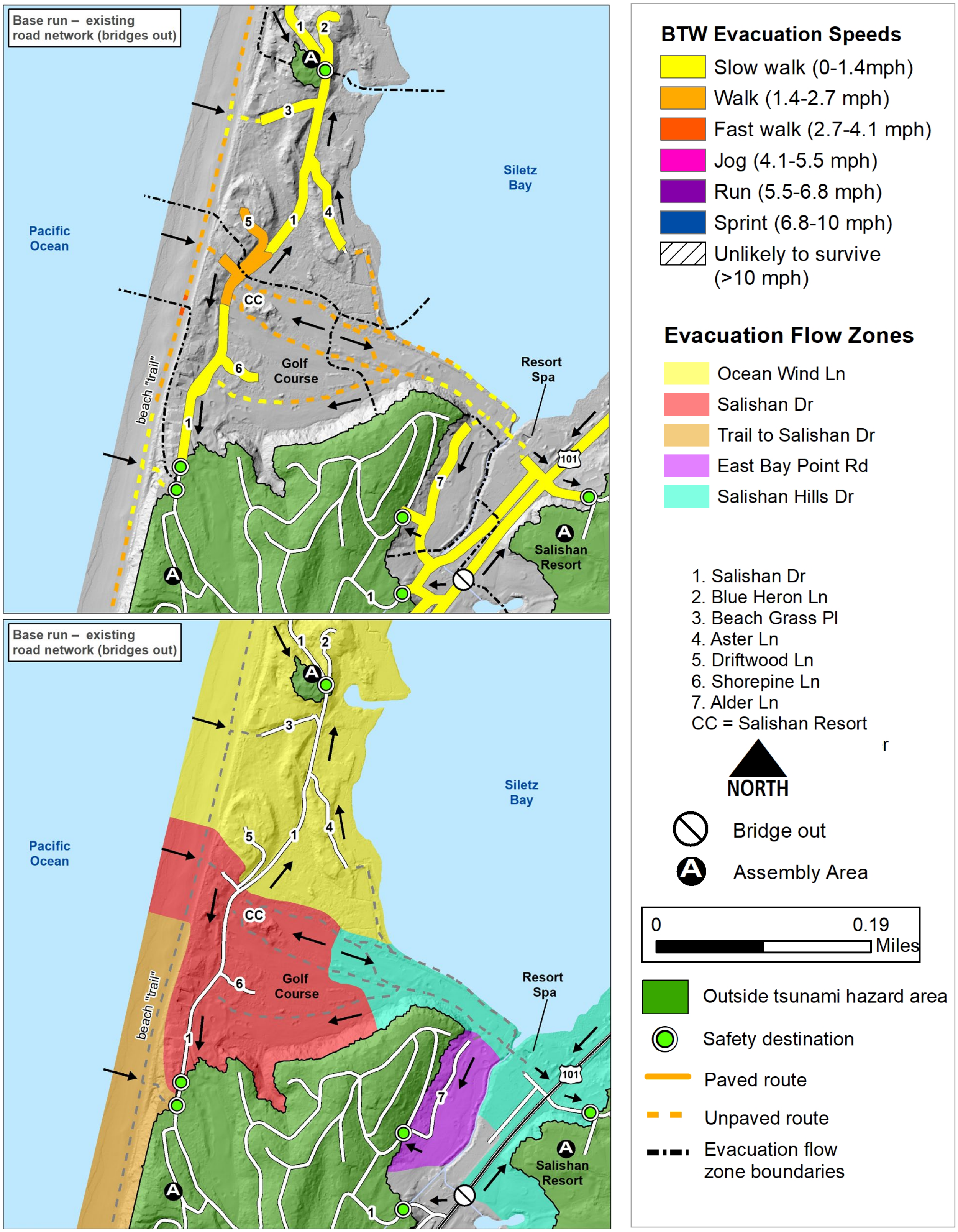
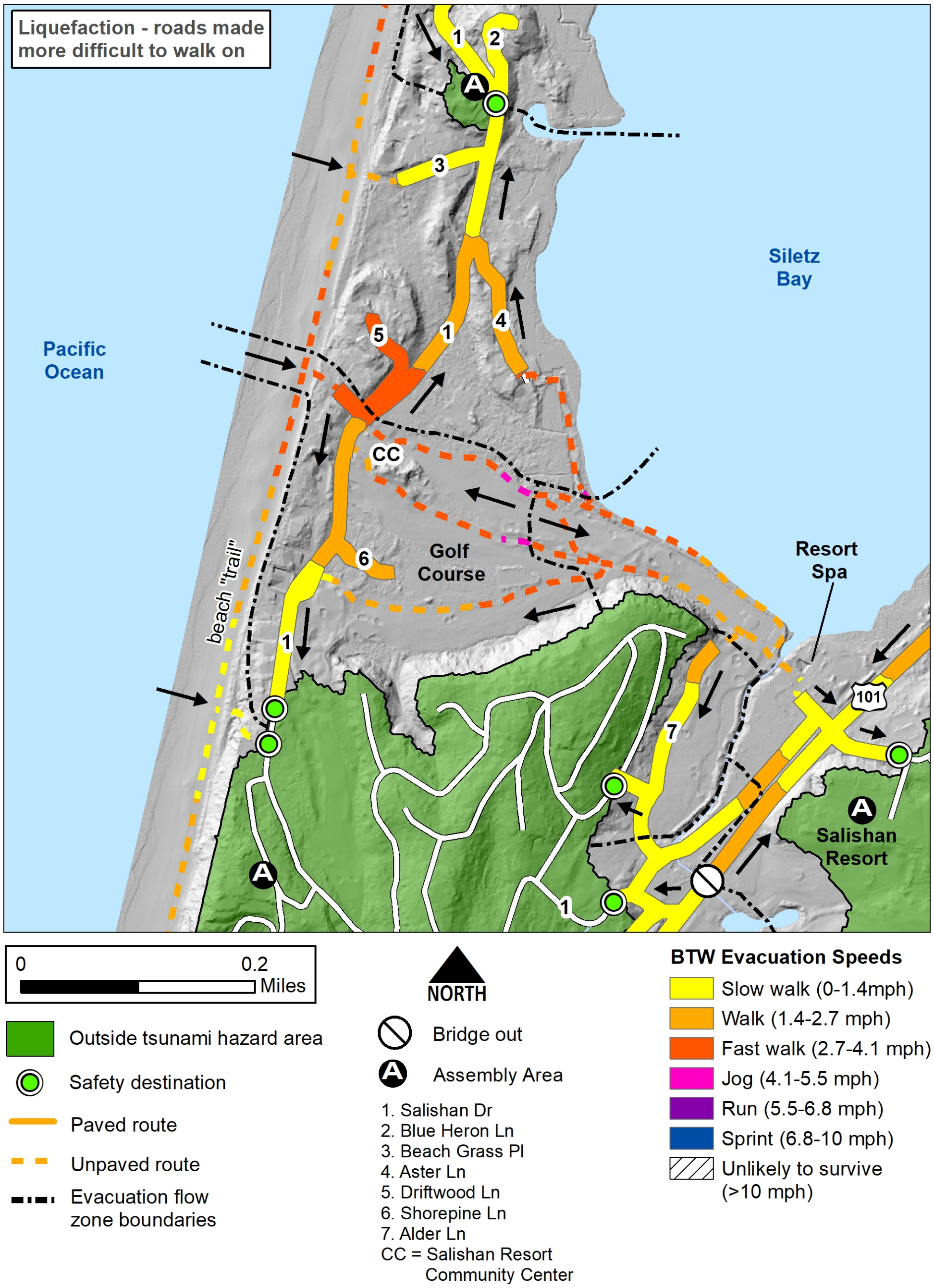


**Figure 3-22. Beat the Wave modeling in Salishan for a liquefaction scenario. Evacuation flow zone boundaries are shown with black dashed lines. Highway 101 bridge over pedestrian underpass assumed to be impassable.**



#### *3.1.2.4 Gleneden Beach*

Despite the fact that nearly all of Gleneden Beach is expected to become inundated during an XXL tsunami, including the Gleneden Beach Fire Station, high ground is nearby and there are numerous safety destinations, resulting in low minimum walking speeds. The tsunami will arrive in ~22 minutes and will advance across Gleneden Beach in approximately 4 minutes (**Figure 3-23**). Nearly everyone can reach safety ahead of the wave at a minimum walking speed of ***slow walk***, with those in a small area around the Worldmark resort needing a speed of ***walk*** (**Figure 3-24**). This scenario assumes the road network remains intact and easily passable. Liquefaction susceptibility is low in this area. Evacuation flow zones are presented in **Figure 3-25**.

**Figure 3-23. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Gleneden Beach (left) North and (right) South.**

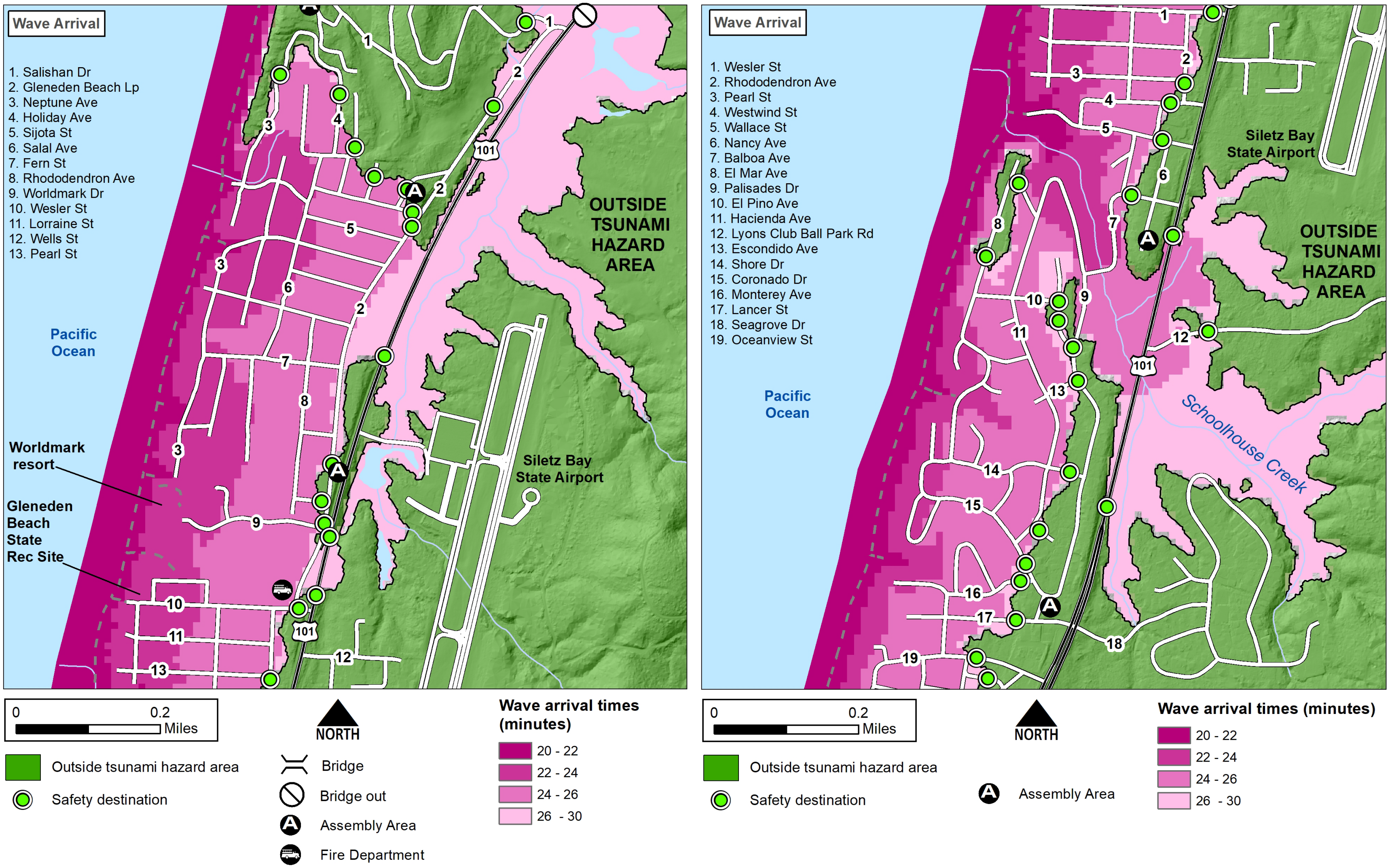


**Figure 3-24. Beat the Wave modeling in Gleneden Beach (left) North and (right) South. Colors on top of the road network reflect <u>minimum BTW walking speeds</u>. Evacuation flow zone boundaries are shown with black dashed lines.**

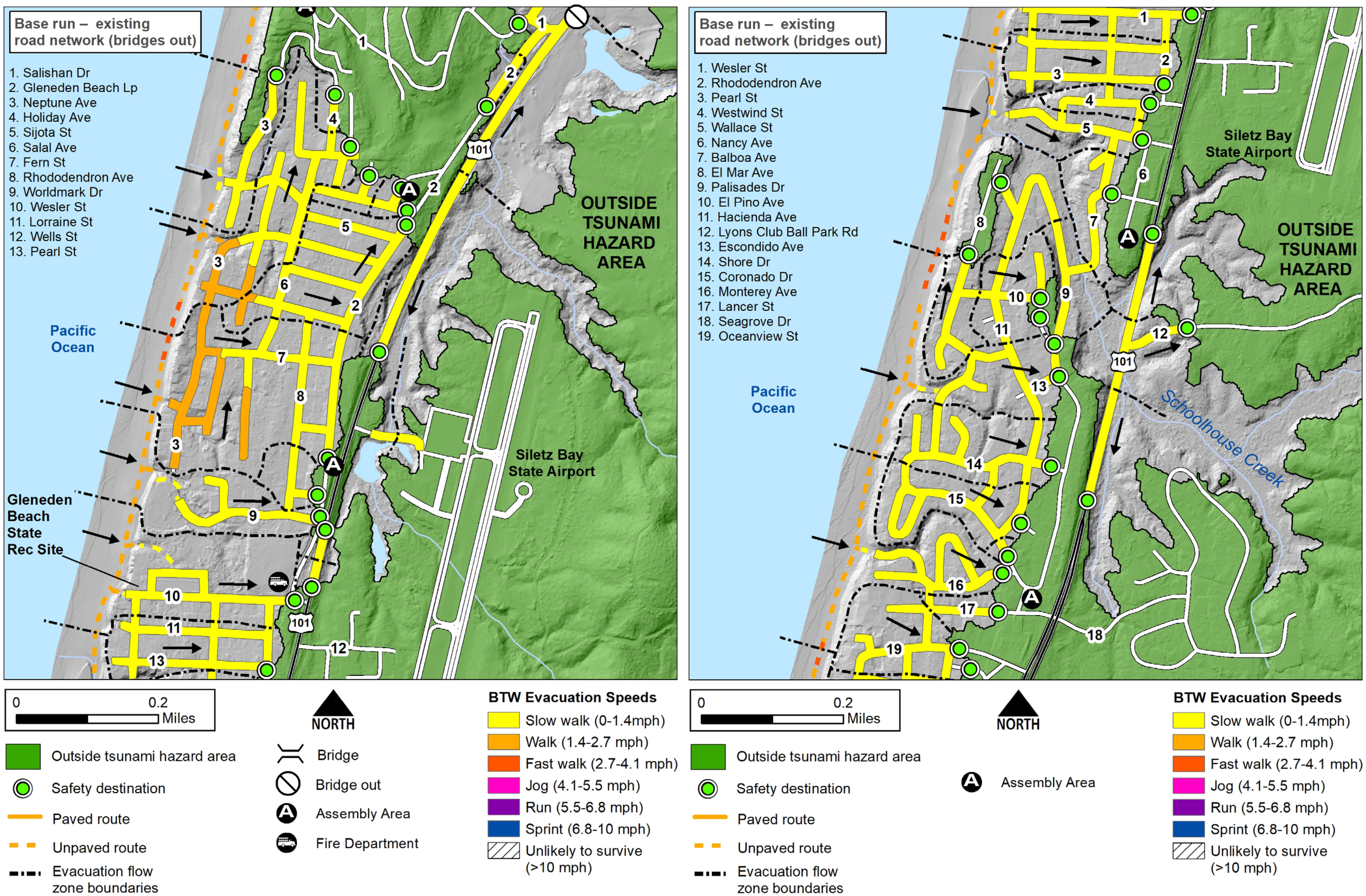
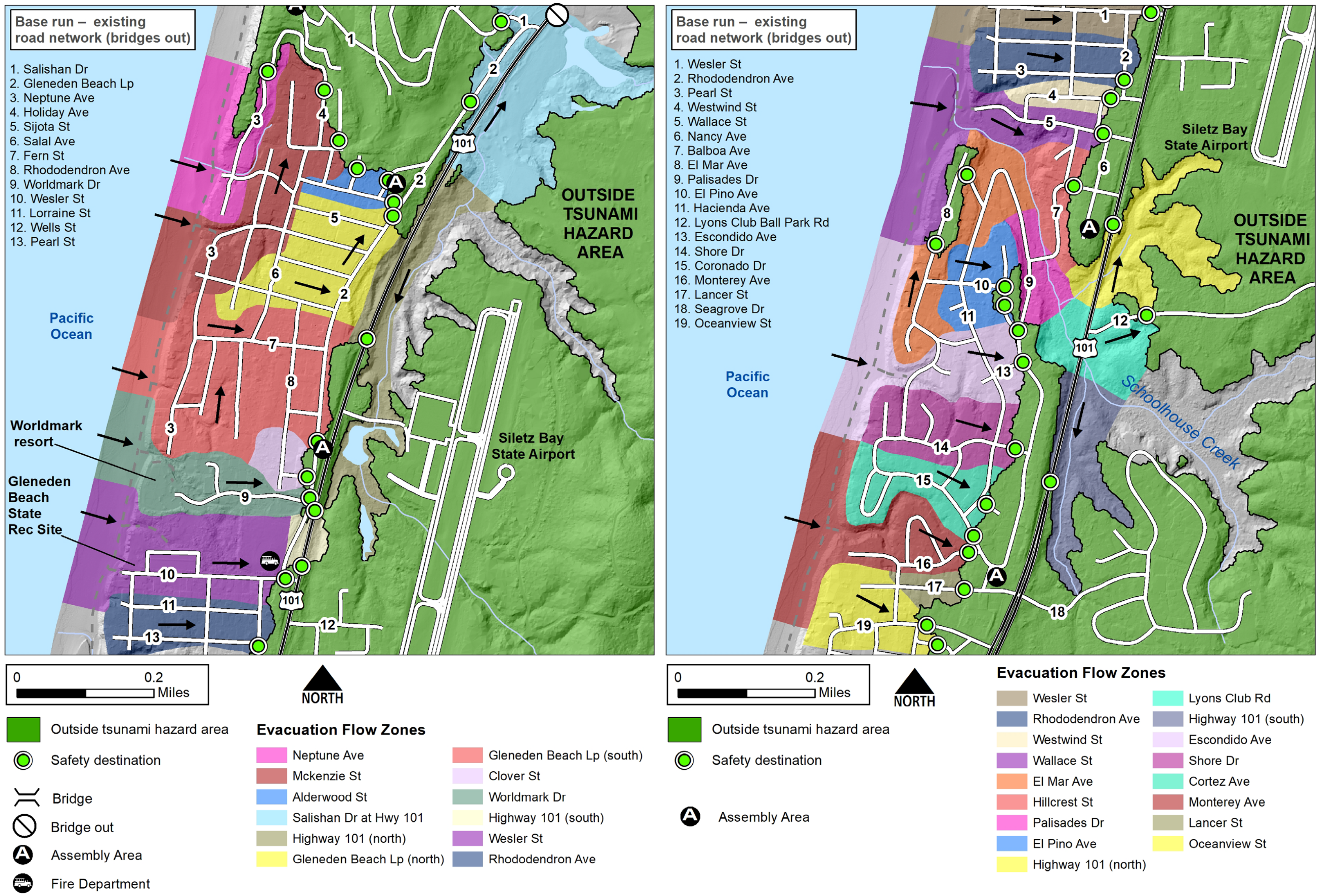


**Figure 3-25. Evacuation flow zones (base scenario) for Gleneden Beach (left) North and (right) South.**



#### *3.1.2.5 Lincoln Beach and Fogarty Creek*

Tsunami wave arrivals and BTW results for Lincoln Beach and Fogarty Creek State Park are virtually identical to Gleneden Beach. The tsunami reaches the beach in 20 minutes and it takes just a few additional minutes to flood the affected area (**Figure 3-26**). A minimum walking speed of ***slow walk*** is needed to beat the wave to safety (**Figure 3-27**). This scenario assumes the road network remains intact and easily passable. Liquefaction susceptibility is low for this area. Evacuation flow zones are presented in **Figure 3-28**.

**Figure 3-26. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for (left) Lincoln Beach and (right) Fogarty Creek.**

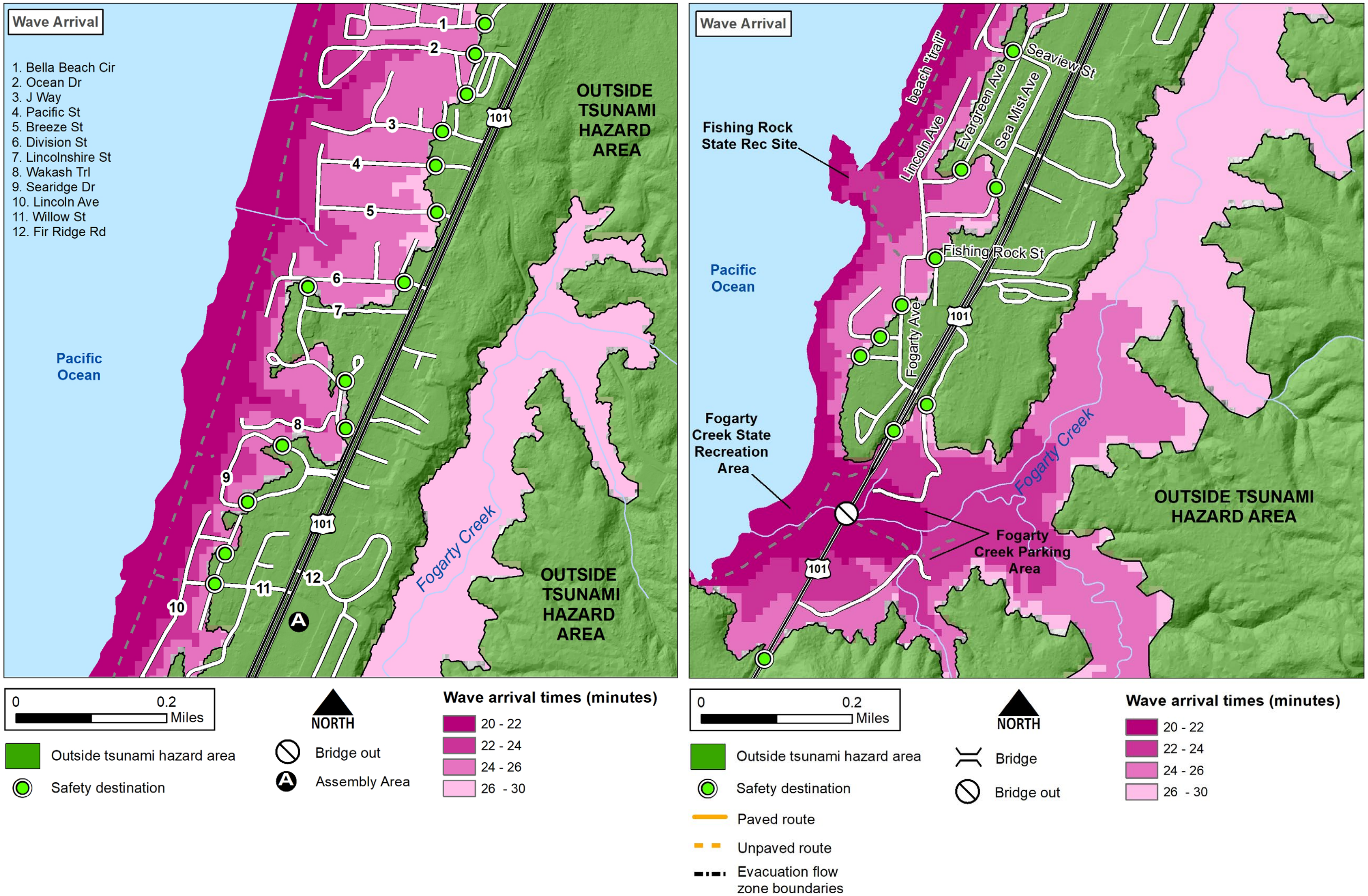


**Figure 3-27. Beat the Wave modeling in (left) Lincoln Beach and (right) Fogarty Creek. Colors on top of the road network reflect minimum BTW walking speeds and evacuation flow zone boundaries are shown with black dashed lines.**

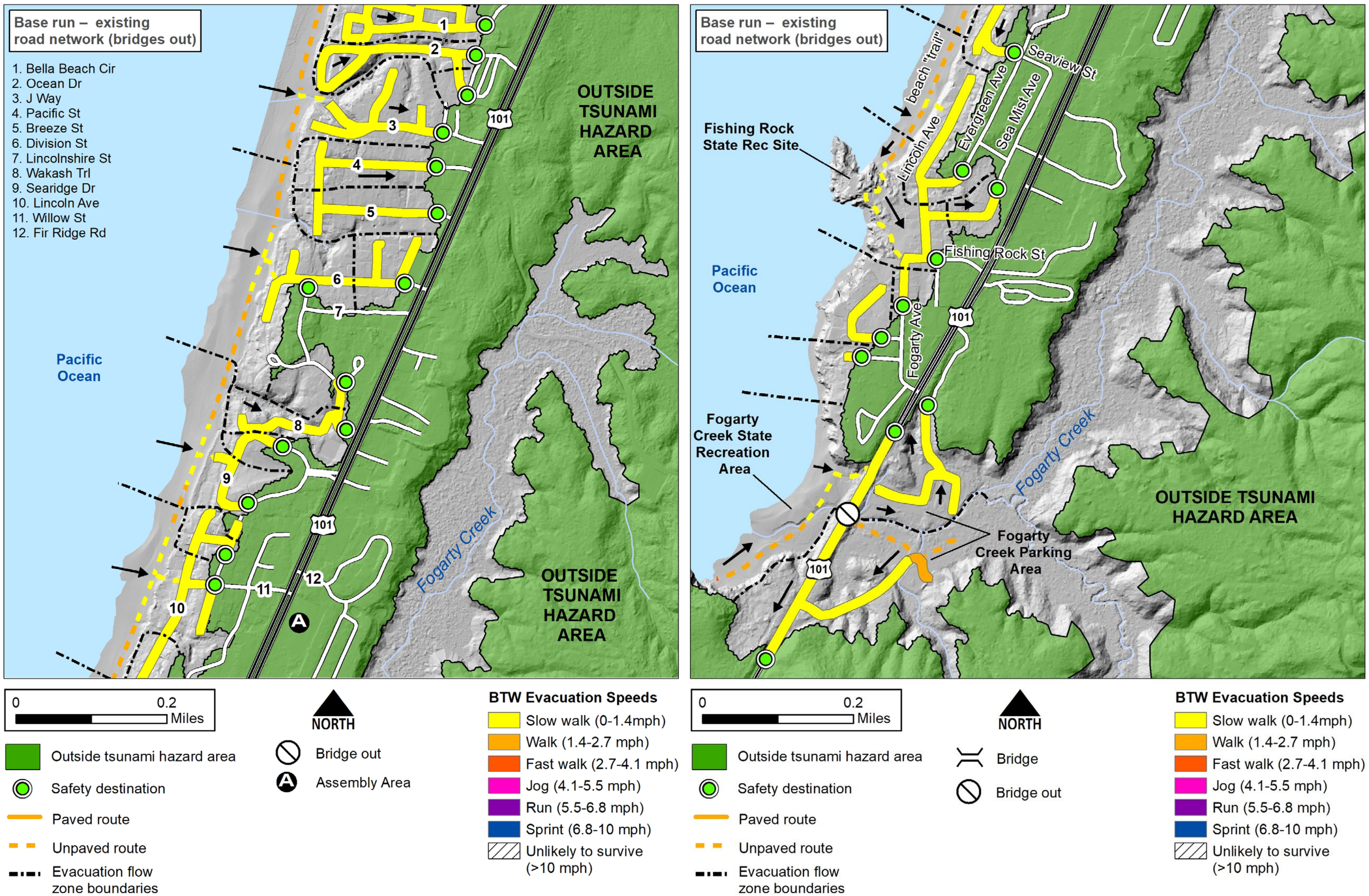
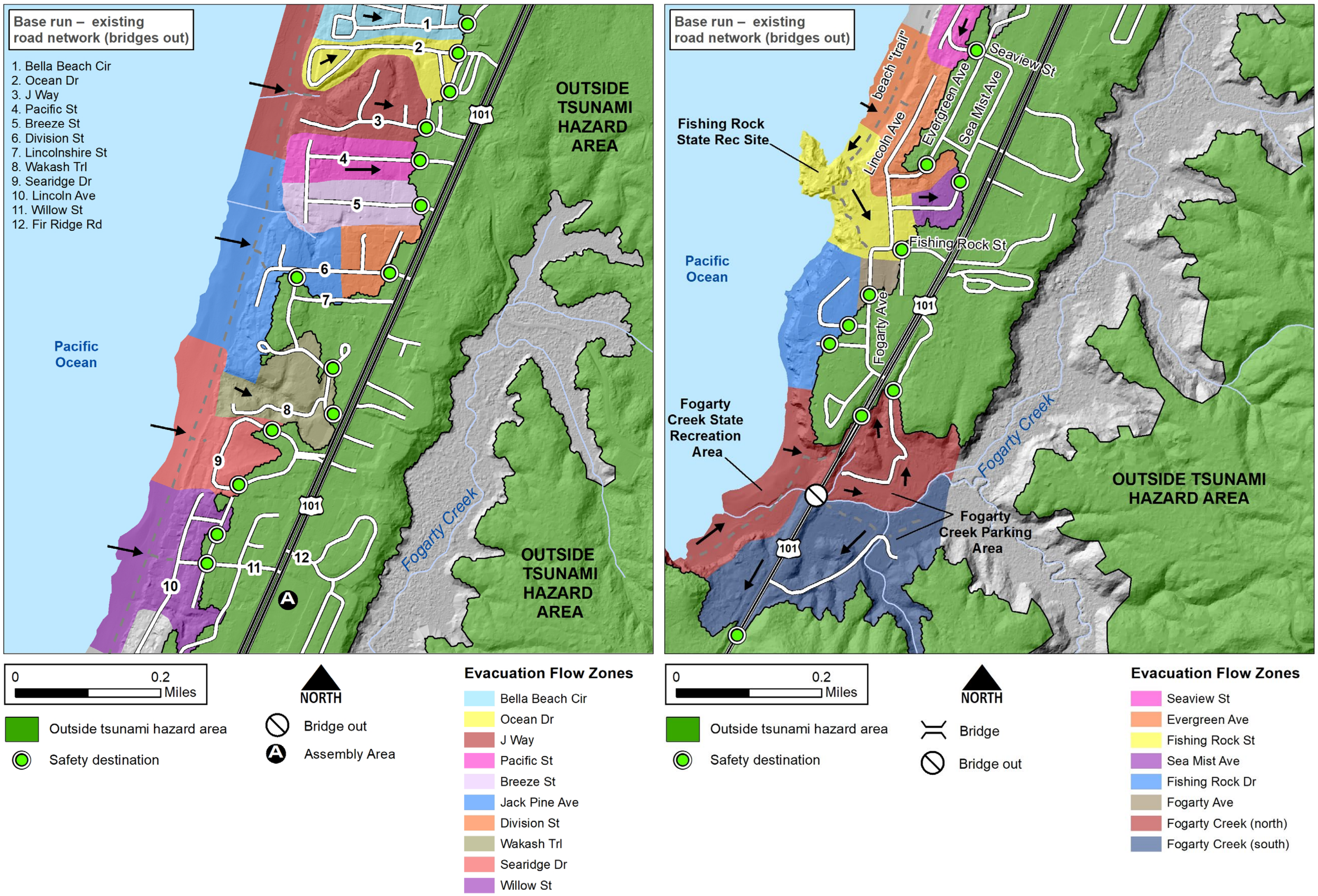


**Figure 3-28. Evacuation flow zones (base scenario) for (left) Lincoln Beach and (right) Fogarty Creek.**



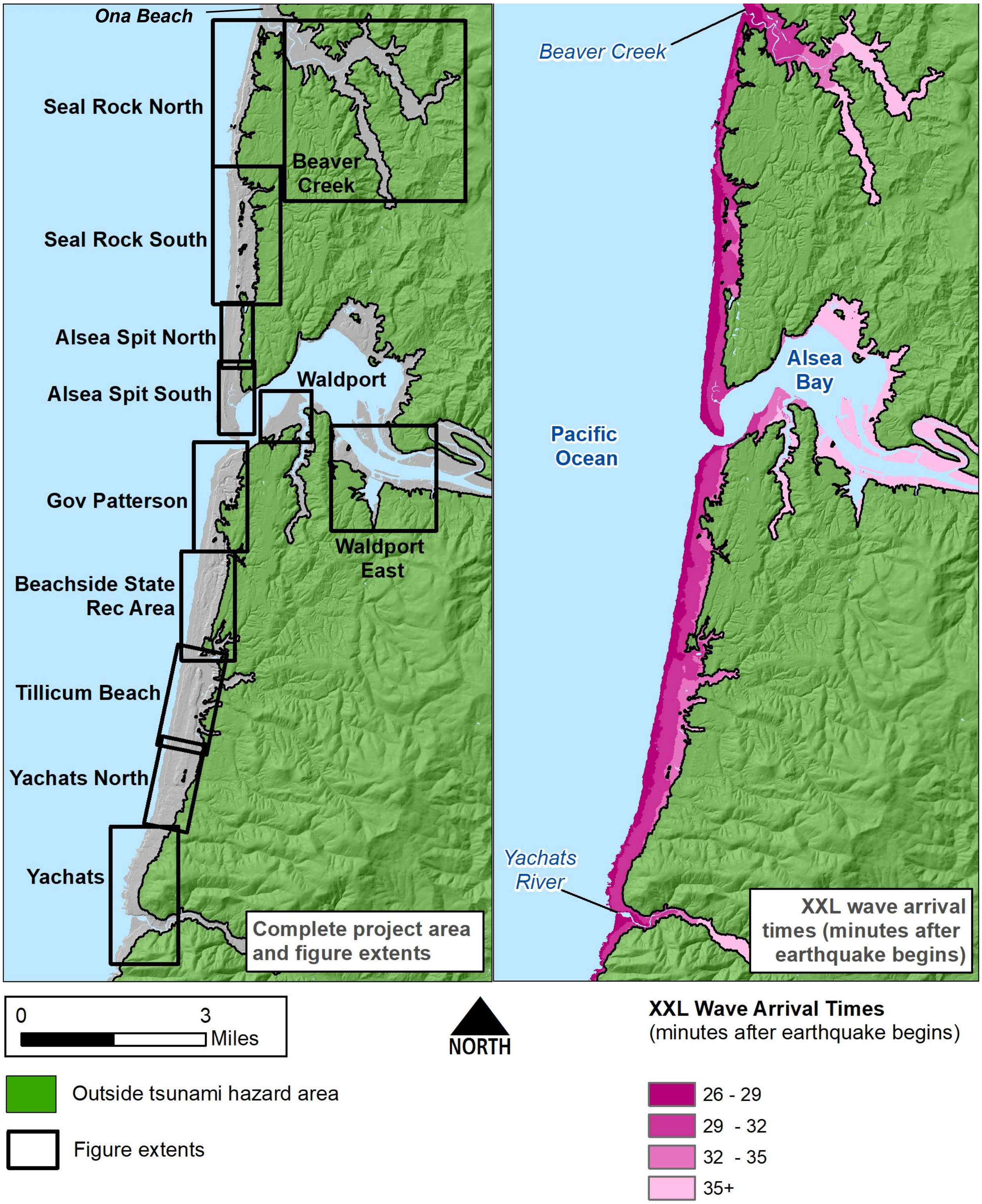
### 3.1.3 South County

The southern region of the study area, from Ona Beach and Beaver Creek in the north to Yachats in the south, can be separated into two distinct geographic styles similar to the Siletz Bay, Gleneden Beach, and Lincoln Beach region: 1) open coast areas characterized by limited inundation, low liquefaction susceptibility and higher elevations and 2) low-lying areas adjacent to Alsea Bay characterized by significant inundation and higher susceptibility to liquefaction. Results are presented separately for each neighborhood (**Figure 3-29, left**).

A regional view of first tsunami wave arrivals is shown in **Figure 3-29, right**. Detailed wave arrival figures are provided for each neighborhood. The first tsunami wave reaches the beach in ~26 minutes and it will take another 5-10 minutes for the open coast to be fully impacted. The tsunami will continue up the estuaries for much longer. Tsunami wave arrival time data are found in the Lincoln_County_ Tsunami_Evacuation_Modeling geodatabase, TsunamiWaveArrival_XXL1 dataset.

Overall, South County requires low minimum walking speeds (<4 fps) to reach safety ahead of the tsunami. The more challenging areas are Alsea Spit and Old Town Waldport, where distances to safety are longer and additional hazards are likely to impede evacuation. As with other neighborhoods presented in this report, the “base” scenario uses the existing road network and excludes any bridges that are not currently built to survive earthquake shaking. Walking speeds on the roads and trails as well as evacuation flow zone data for the base scenario are found in the Lincoln_County_Tsunami_Evacuation_Modeling geodatabase, XXL1_BridgesOut feature dataset.

**Figure 3-29. (left) South County area map showing figure extents. (right) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for South County. Gov Patterson is Governor Patterson Memorial State Recreation Site.**



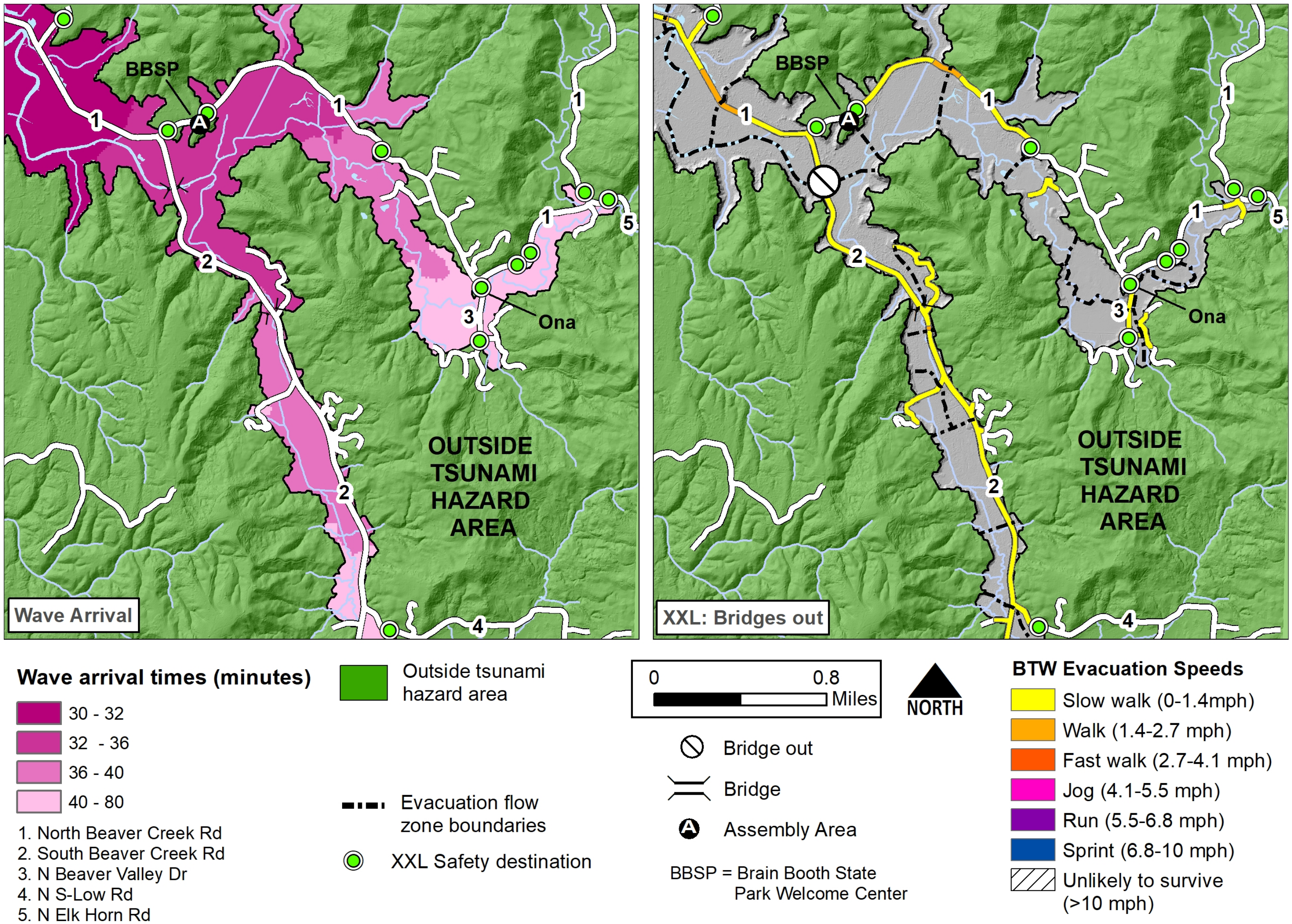
#### *3.1.3.1 Beaver Creek*

Despite the fact that the Beaver Creek estuary is expected to be fully inundated during an XXL tsunami, nearly all residences as well as Brian Booth State Park Welcome Center are outside the XXL inundation zone. Therefore, these results are relevant only for the relatively small number of residences inside the zone as well as people who find themselves on a road, in the marsh itself, or at the boat launch (not shown) during the earthquake.

**Figure 3-30, left** presents first tsunami wave arrival times for the estuary. It takes about 40 minutes for most of the flooding to occur; however, over the course of another ~40 minutes additional marshland upstream will be impacted. Inundation terminates about one mile north of the town of Ona on North Beaver Creek at the intersection of N Beaver Creek Road and N Elk Horn Road and just past N-S Low Road on South Beaver Creek (not shown).

**Figure 3-30, right** presents BTW results for Beaver Creek. All but 0.3 miles of North and South Beaver Creek Roads are classified as ***slow walk*** (2 fps or 1.4 mph), which is because these roads follow the edge of the estuary and generally there is opportunity to take a side road uphill and almost immediately be outside the zone.

**Figure 3-30. (left) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Beaver Creek. (right) Beat the Wave modeling in Beaver Creek for base scenario. Colors on top of the road network reflect minimum BTW walking speeds. Black dashed lines define evacuation flow zone boundaries.**



#### *3.1.3.2 Seal Rock*

The neighborhood of Seal Rock itself is almost entirely outside of the hazard area. However, Highway 101 as well the Seal Rock Fire District Station and the streets immediately south of Seal Rock are inside the tsunami zone. The first tsunami wave arrivals reach the beach ~26 minutes after earthquake shaking begins, and within another 5–10 minutes the entire area is expected to be inundated (**Figure 3-31**). As with several other neighborhoods in Lincoln County that can be characterized as having a narrow inundation area, high ground can be reached relatively easily; minimum BTW walking speeds are ***slow walk*** (2 fps, or 1.4 mph) for the entire area (**Figure 3-32**). Evacuation flow zones are provided in **Figure 3-33**.

**Figure 3-31. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Seal Rock (left) North and (right) South.**

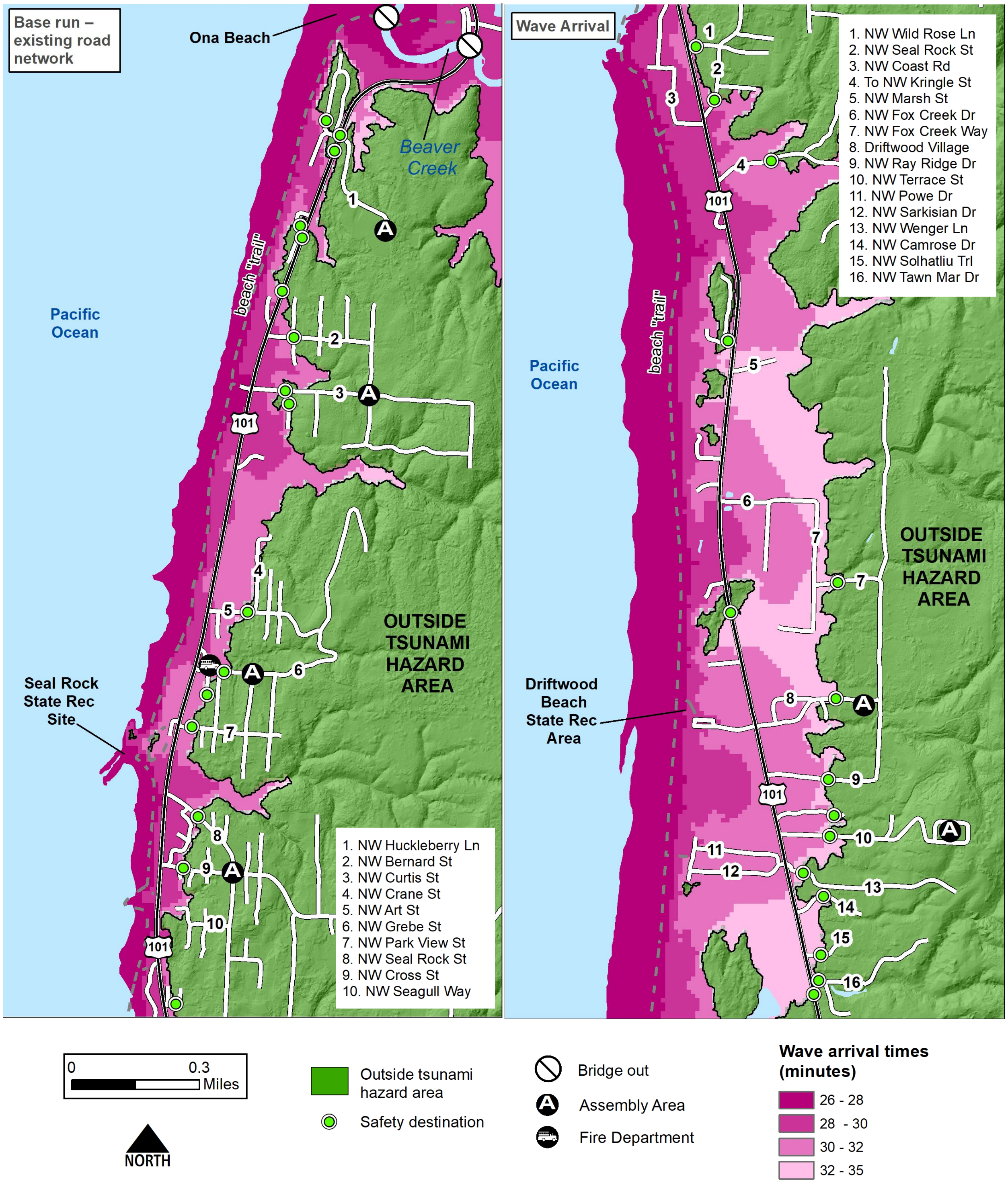


**Figure 3-32. Beat the Wave modeling of base scenario in Seal Rock (left) North and (right) South. Colors on top of the road network reflect minimum BTW walking speeds and evacuation flow zone boundaries are shown with black dashed lines.**

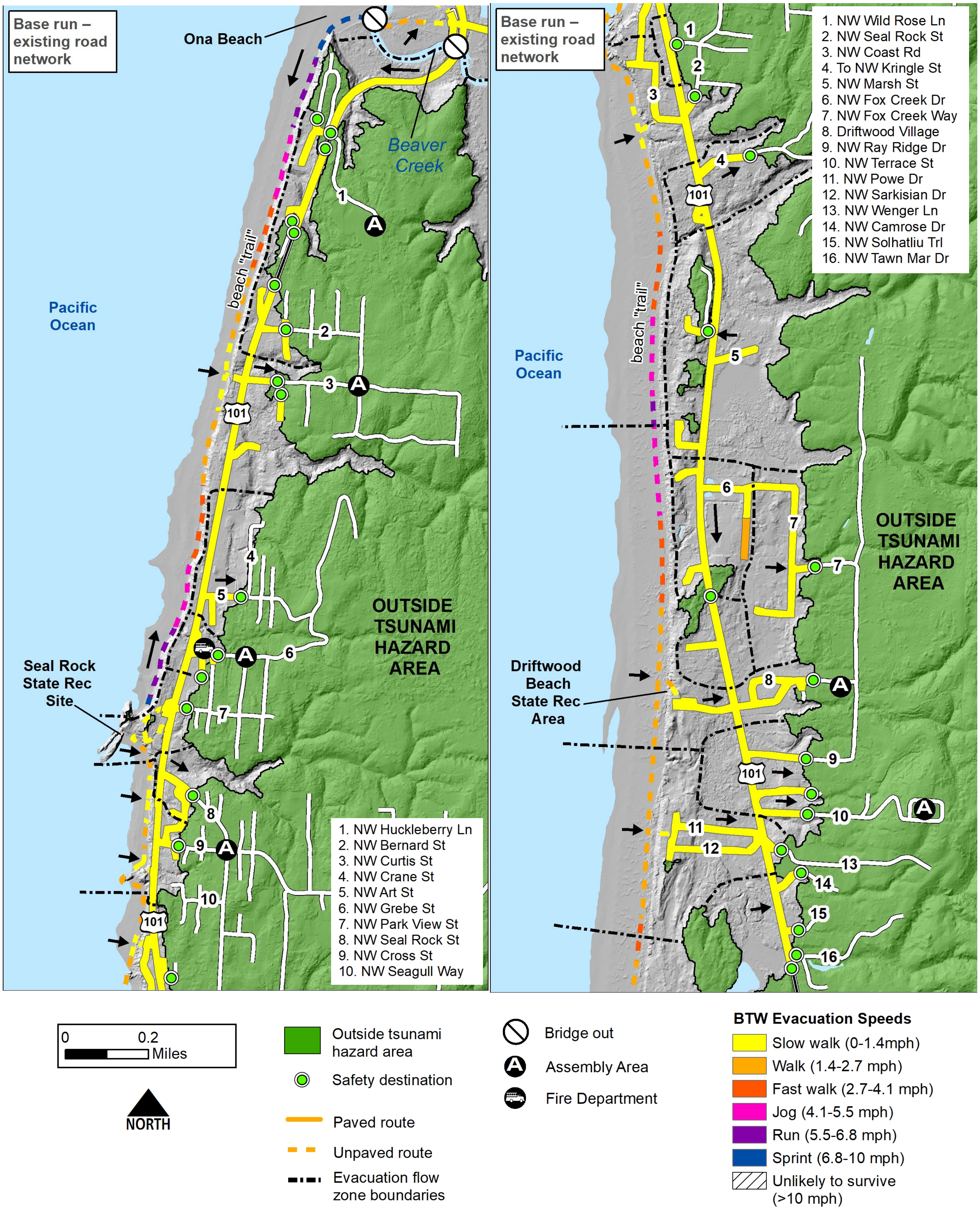
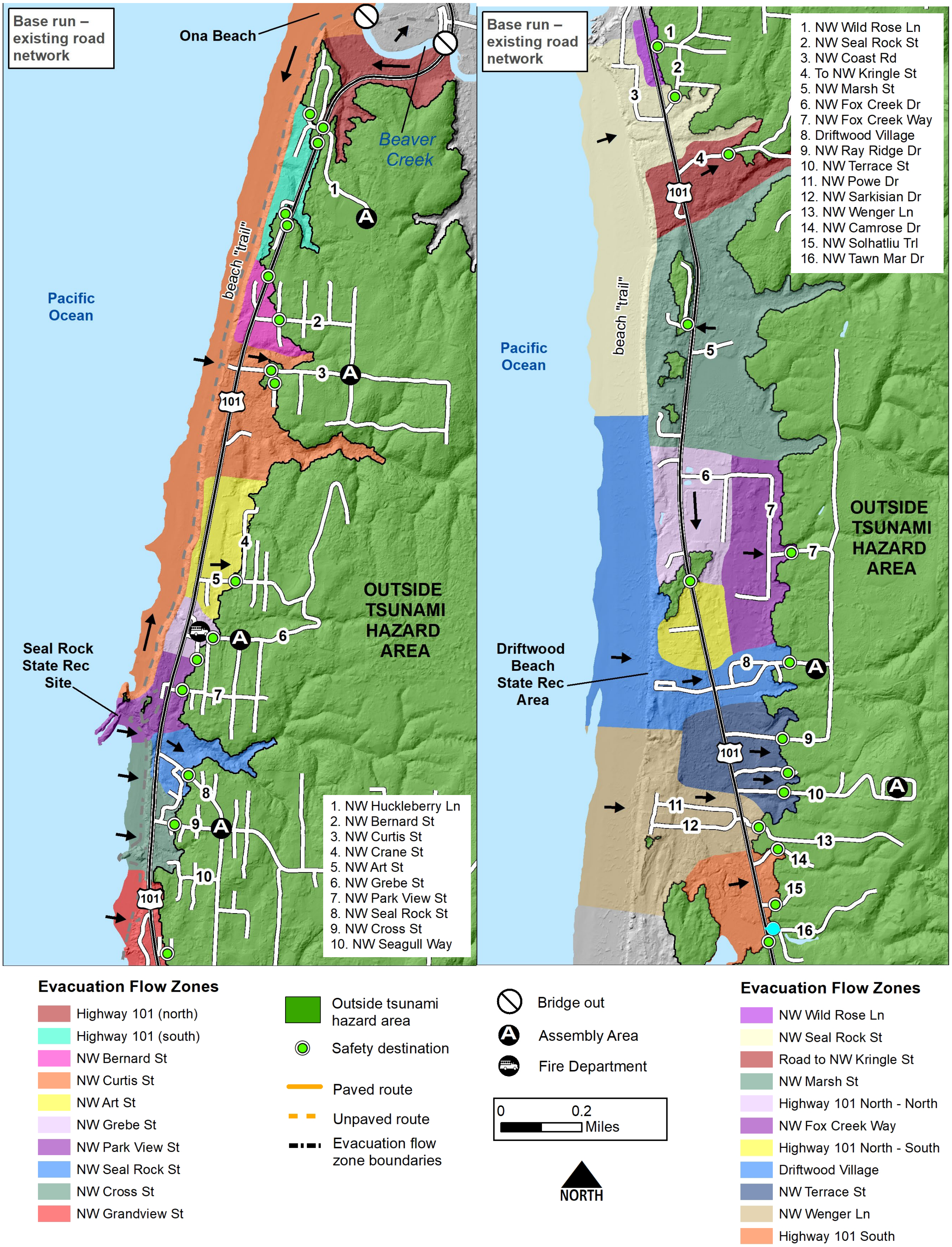


**Figure 3-33. Evacuation flow zones (base scenario) for Seal Rock (left) North and (right) South.**



#### *3.1.3.3 Alsea Spit*

For this project, Alsea Spit is defined as the area from the mouth of Alsea Bay in the south to NW Hidden Lake Drive in the north. This area is also known as the Bayshore community. The northern half of this area is not actually on the spit, and high ground can be found due east of the residential area on any number of paved roads. The southern half, on the spit itself, will be completely overtopped by an XXL tsunami, and the nearest high ground is about one mile north of the mouth on Bayshore Dr as the road climbs uphill to connect with Highway 101. The first tsunami wave arrives in ~26 minutes, and the entire area is flooded by ~32 minutes (**Figure 3-34**).

**Figure 3-35** presents results for the base BTW scenario. Under ideal conditions, the evacuees in northern area can reach high ground at a ***slow walk*** and ***walk***, which is unsurprising given the proximity to high ground. The spit itself has a significant amount of ***slow walk*** and ***walk*** speeds as well; however, the single safety destination on Bayshore Drive becomes increasingly difficult to reach farther down the spit evacuees are, with minimum speeds as high as ***fast walk*** (6 fps or 4.1 mph) required at the southern end. Evacuation flow zones for the base scenario are presented in **Figure 3-36**.

As with other low-lying coastal areas, liquefaction is expected to occur in this area during earthquake shaking. **Figure 3-37** presents minimum walking speeds representing the added walking difficulty due to standing water, sand, and mud. Minimum walking speeds at the southern end of the spit increase to ***run*** (10 fps or 6.8 mph) in this scenario. Because mitigation of this hazard is especially difficult, our results emphasize the importance of beginning evacuation promptly and knowing which direction to walk to avoid losing time by taking wrong turns. As discussed in section 2.2, liquefaction is site specific and does not always affect a region equally everywhere. Therefore, this is a conservative look at how liquefaction may affect evacuation.

A secondary safety destination at the Waldport/Newport Kampground of America (KOA) can be reached via private road off NW Bayshore Drive (near NW Admiralty Circle). **Figure 3-38** highlights the improvements this trail would bring to the neighborhood if it were a sanctioned and signed route, reducing minimum walking speeds by one classification. The most significant improvement is at the southern tip of the spit, where speeds on half of the streets are reduced from ***fast walk*** to ***walk***.

**Figure 3-34. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake at Alsea Spit (left) North and (right) South. KOA is Waldport/Newport Kampground of America.**

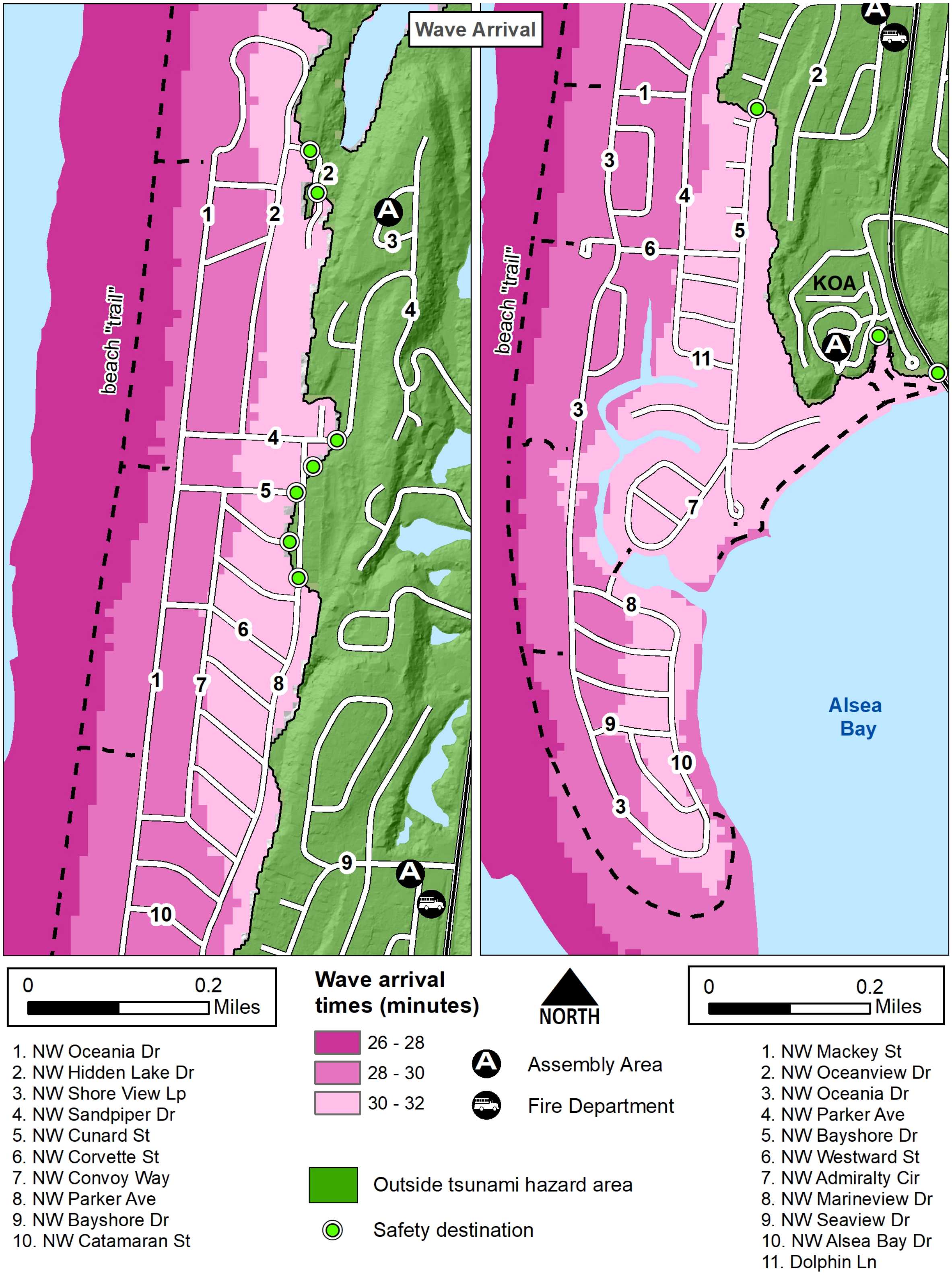


**Figure 3-35. Beat the Wave modeling of base scenario at Alsea Spit (left) North and (right) South. Colors on top of the road network reflect minimum BTW walking speeds and evacuation flow zone boundaries are shown with black dashed lines. KOA is Waldport/Newport Kampground of America.**

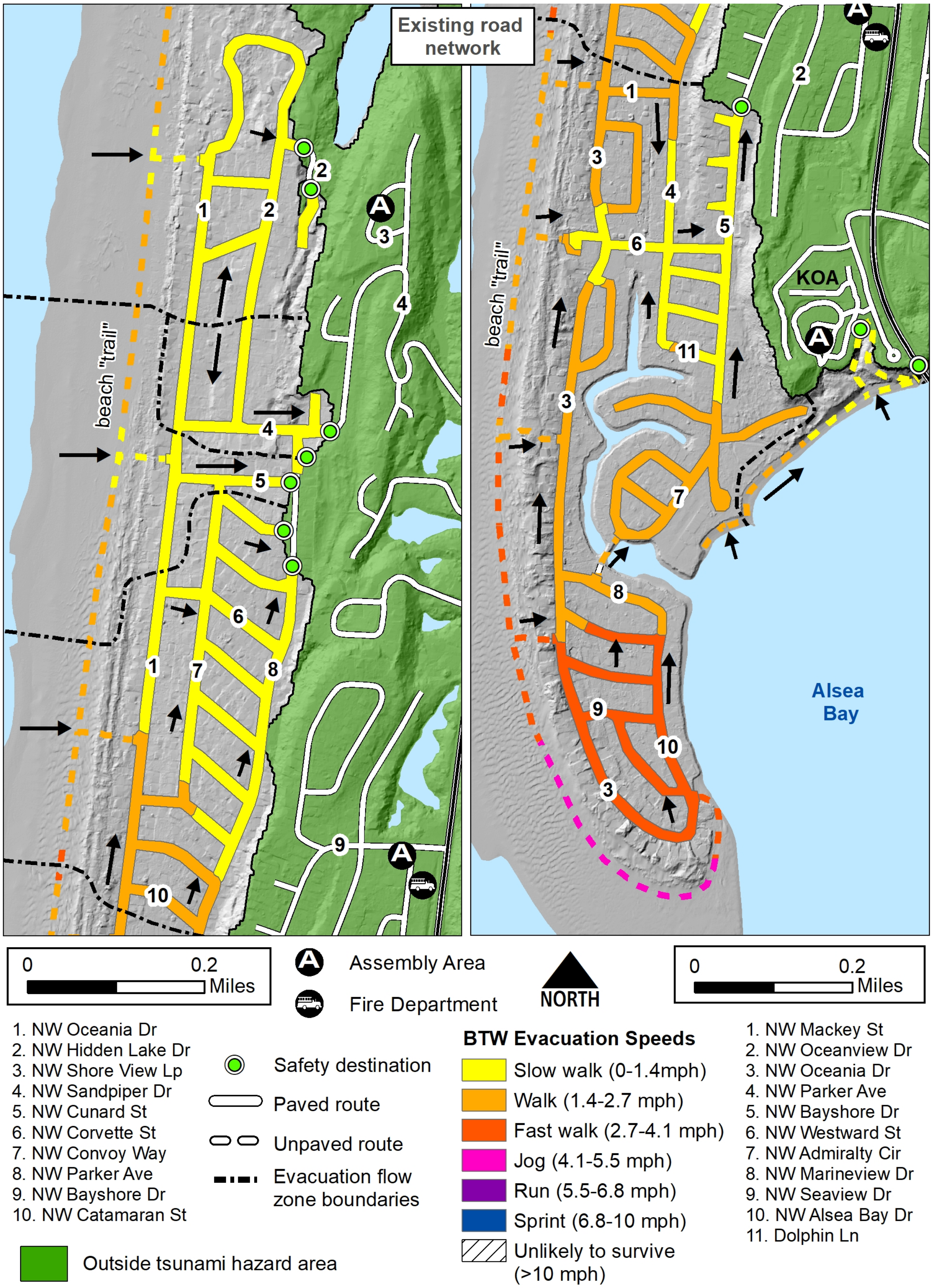


**Figure 3-36. Evacuation flow zones (base scenario) for Alsea Spit (left) North and (right) South. KOA is Waldport/Newport Kampground of America.**

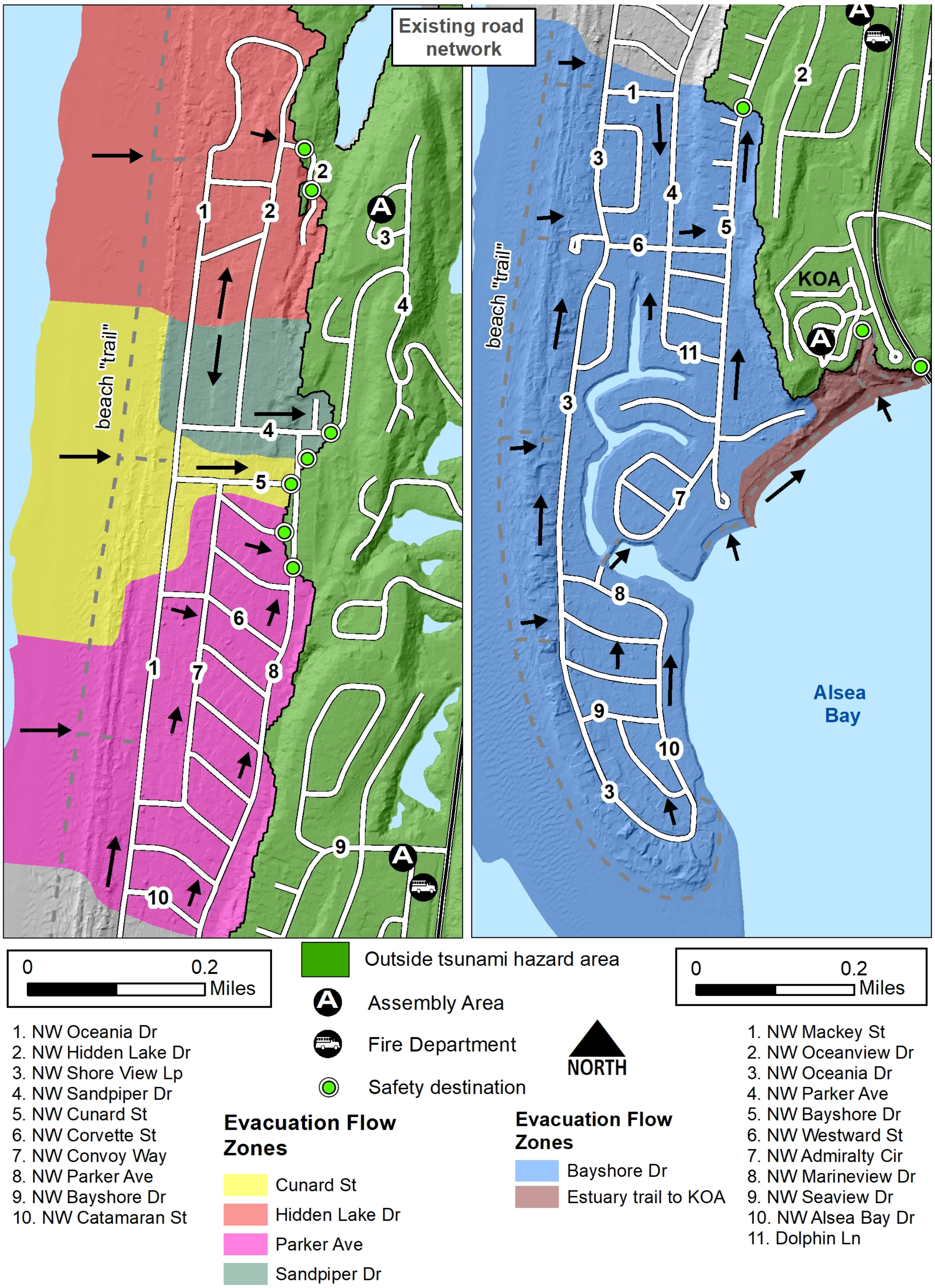


**Figure 3-37. Beat the Wave modeling of a hypothetical liquefaction scenario at Alsea Spit (left) North and (right) South. KOA is Waldport/Newport Kampground of America.**

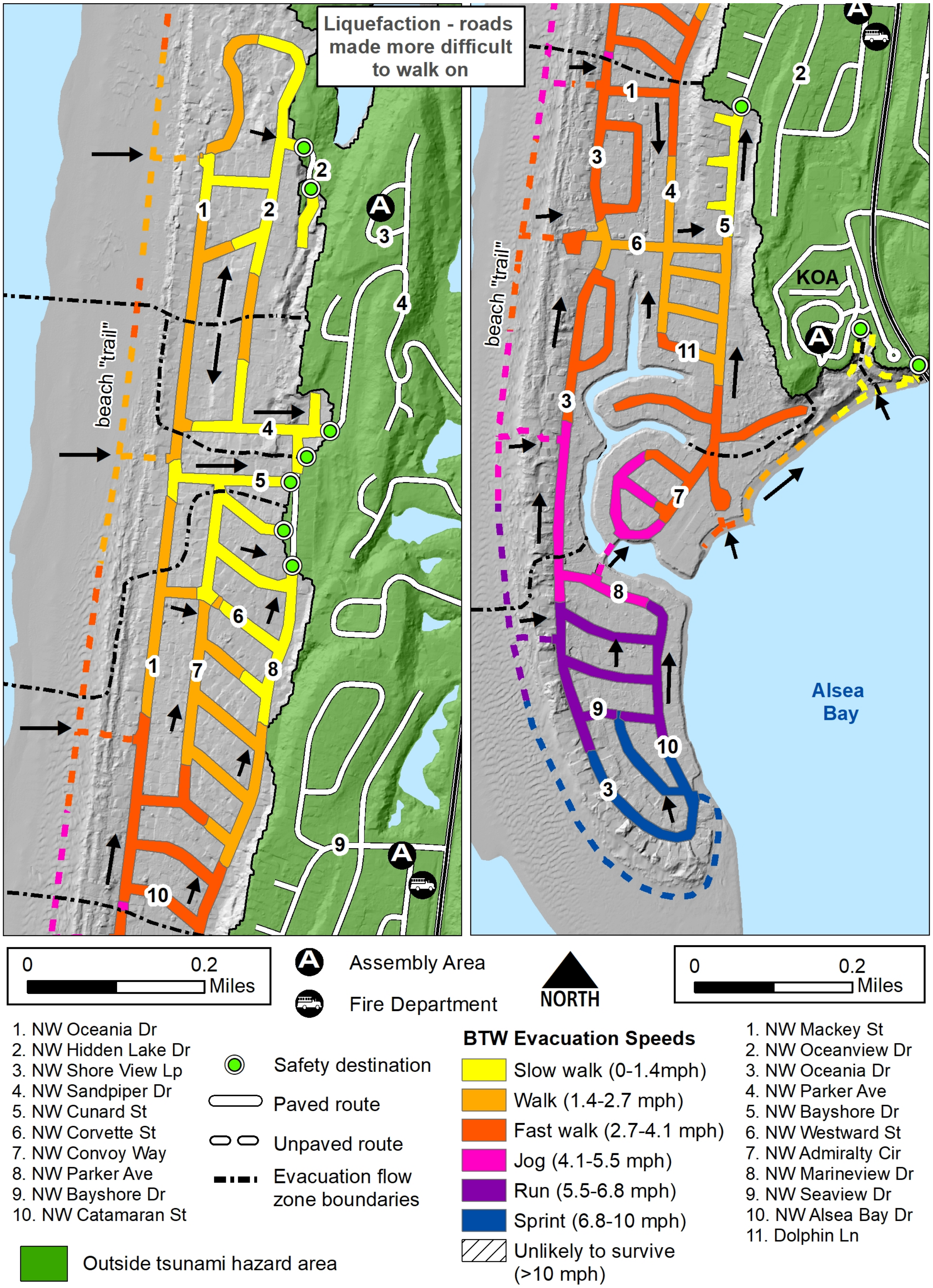
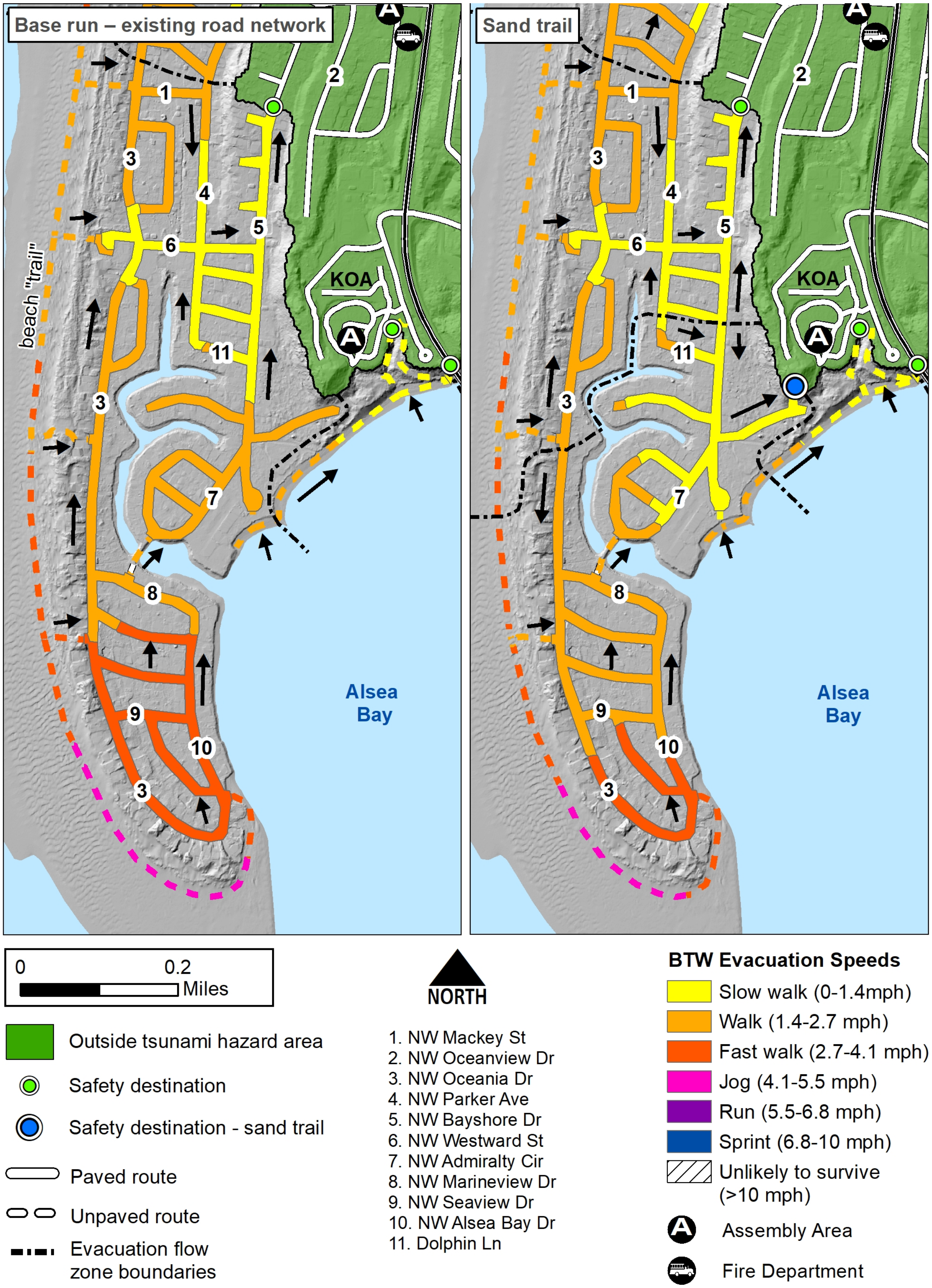


**Figure 3-38. Beat the Wave modeling of a hypothetical trail to Waldport/Newport Kampground of America (KOA) for Alsea Spit South.**



#### *3.1.3.4 Waldport*

The town of Waldport is located on the southern shore of Alsea Bay about 0.5 miles inside the mouth. Highway 101, the business district, the neighborhood of Old Town, the Port of Alsea, and the Central Coast District Fire Station are all expected to be inundated by an XXL tsunami. The business district is the stretch of Highway 101 between the Alsea Bay Bridge and the seawall. Old Town is the neighborhood north of Highway 34, east of Highway 101, and west of Lint Slough. High ground can be found to the south along Crestline Drive. The tsunami reaches the west edge of town ~30 minutes after the start of earthquake shaking and by 36 minutes has flooded the community and is continuing up the Alsea River and Lint Slough (**Figure 3-39, left**).

The base run for Waldport reflecting current road conditions does not allow for evacuation across the Alsea Bay Bridge (Highway 101) or Lint Slough (Highway 34). This is referred to as “bridges out” in the digital data. Neither of these bridges have been constructed in a manner that suggests they will survive the earthquake shaking. Therefore, we first present results assuming evacuation cannot rely on passage across these bridges. **Figure 3-40, top left** show minimum BTW walking speeds of ***slow walk*** for all but a few blocks near the port, from which area evacuees must travel at a ***walk***. Evacuation flow zones for this scenario are provided in **Figure 3-39, right**.

**Figure 3-40, top right** presents a scenario where both bridges are available for evacuation. This scenario represents a hypothetical seismic retrofit of these bridges or simply that in their current state they do not fail during the earthquake. BTW walking speeds are nearly identical to the base scenario without these bridges, which reveals that neither of these bridges are necessary for evacuation purposes.

Liquefaction will present an additional challenge for Waldport. **Figure 3-40, bottom left** shows that minimum walking speeds will increase from ***slow walk*** to ***walk***, with several blocks near the port increasing to ***fast walk***.

Further complications may arise if evacuation routes are blocked by landslides. The hills along Crestline Drive are steep, and slope instabilities are common. After a significant earthquake, slopes are expected to be even more unstable and landslides may occur. To evaluate this hazard with BTW modeling, we remove roads from the model, forcing evacuation elsewhere. Four main roads lead to high ground: Crestline Dr, Cedar St, Pacific View, and Norwood Dr. On the basis of previous landslide locations, communication with local stakeholders, and our geological judgement, we chose to remove the Crestline and Cedar routes. This scenario requires everyone in Old Town to walk up Pacific View or Norwood Dr. **Figure 3-40, bottom right** shows that minimum BTW walking speeds are very similar to the liquefaction scenario: evacuees from much of town must travel at a minimum speed of ***walk***, with the extreme areas requiring ***fast walk***. In reality, evacuees may have to walk over landslide terrain as best they can to reach high ground if no roads are available to them and there is not time to walk around the landslide to find a new route.

Overall, BTW results in Waldport are encouraging. Even with liquefaction, most of town can reach safety at a minimum speed of 4 fps or less. However, prompt evacuation, knowing the route, considering alternative routes due to landslide activity, and signage are key to survival.

**Figure 3-39. (left) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Waldport. (right) Evacuation flow zones (base scenario) for Waldport.**

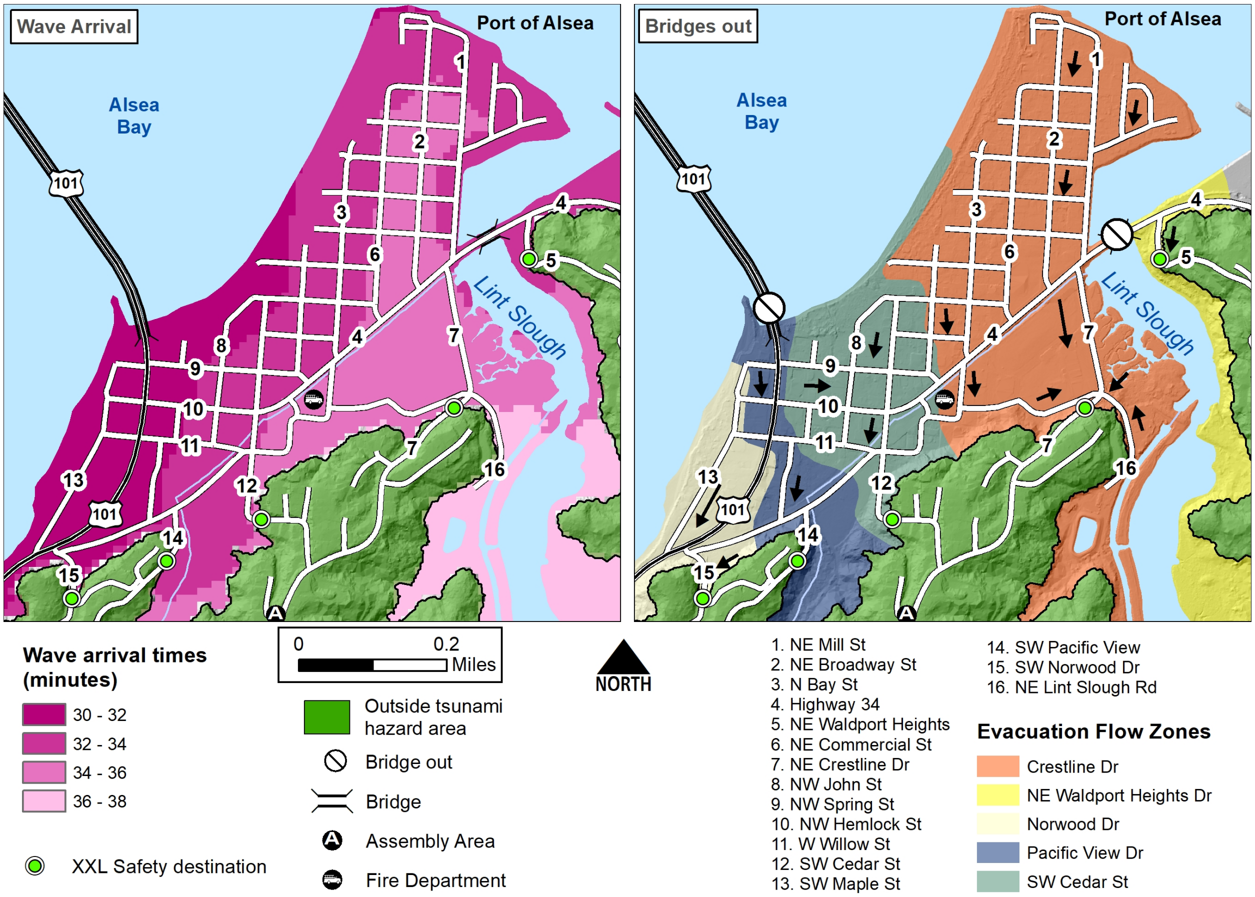
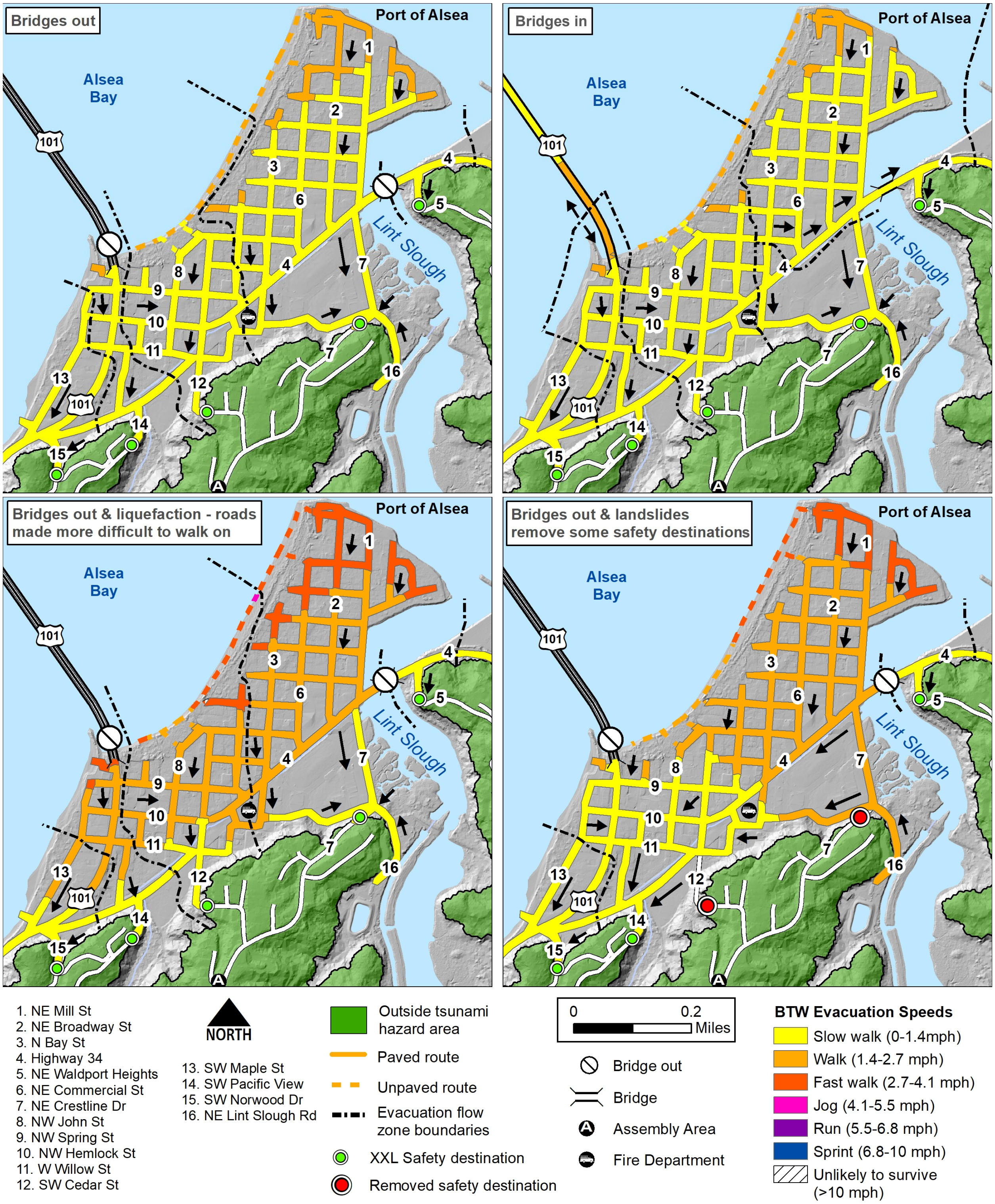


**Figure 3-40. Beat the Wave modeling of four scenarios in Waldport: (top left) Existing road network (Alsea Bay and Lint Slough bridges are "out"); (top right) bridges "in" (hypothetical retrofitted bridges); (bottom left) liquefaction included; and (bottom right) hypothetical landslide difficulties (Crestline Dr and Cedar St unavailable).**



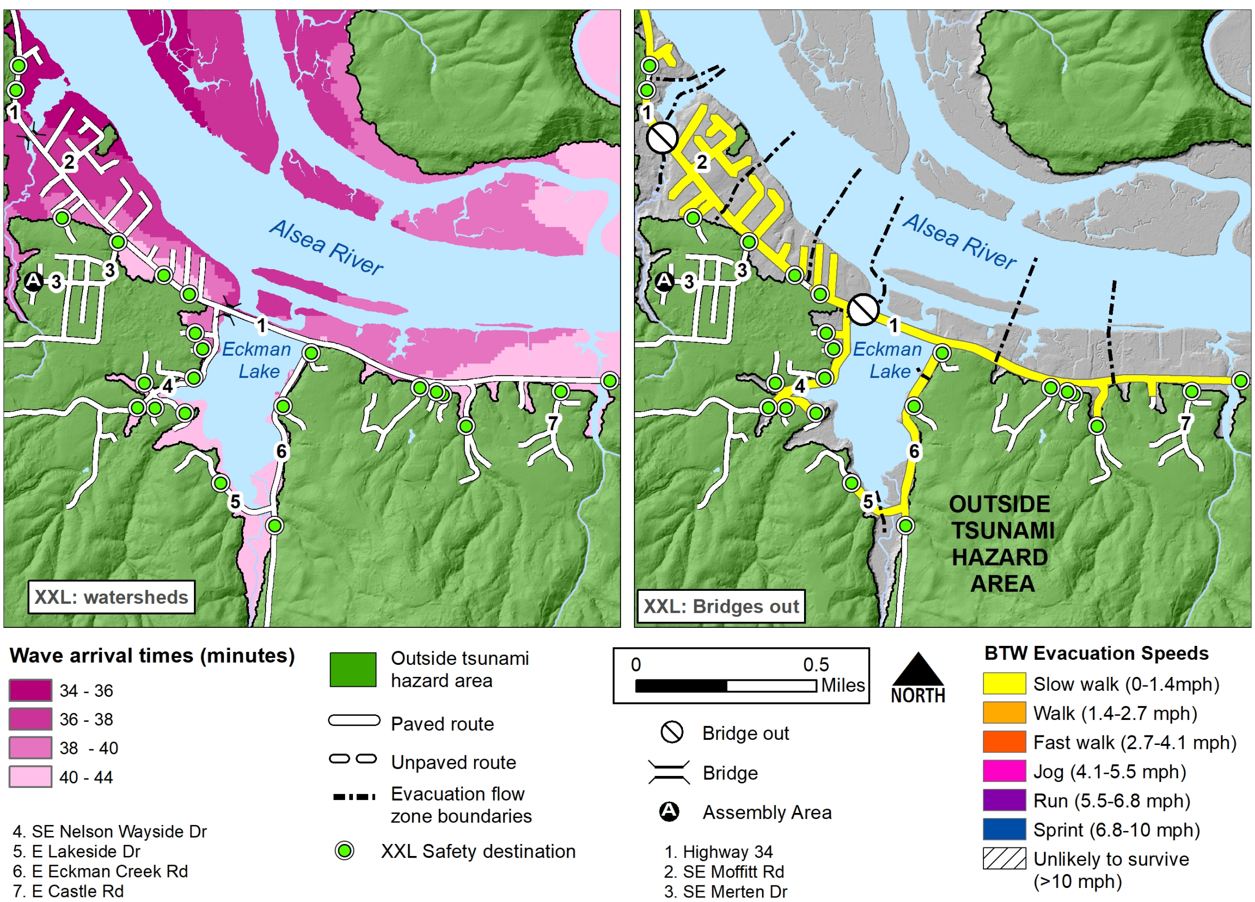
### *3.1.3.5 Waldport East*

The streets off Highway 34 east of Waldport are just inside the inundation zone. The neighborhood has short distances and many options to reach high ground; however, lateral spreading due to the river may be an added hazard.

The tsunami reaches the western end of this area (Moffitt Rd) in ~34 minutes (**Figure 3-41, left**), passes Castle Rd by 40 minutes, and continues upriver another ~8 miles to about 2 miles beyond Tidewater (not shown). **Figure 3-41, right** presents BTW results for this area. Because high ground is almost immediately available on the landward side of Highway 34, evacuees can reach safety ahead of the wave with minimum walking speed of ***slow walk*** (2 fps or 1.4 mph).

Liquefaction and lateral spreading will likely increase evacuation difficulty in this area; however, we chose not to model liquefaction due to the extremely short distances to safety. We have seen in similar locations that applying liquefaction to an area like this results in no change to BTW walking speeds. Instead, we recommend site-specific studies to assess concerns over these earthquake hazards and how they might impact evacuation.

**Figure 3-41. (left) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake for Waldport East. (right) Beat the Wave modeling of base scenario in Waldport East.**



#### *3.1.3.6 Governor Patterson and Beachside state recreation areas*

South from Waldport the pattern of inundation is a common one in Lincoln County: a relatively narrow strip of inundation backed by high ground and a lower likelihood of liquefaction. In the area of Governor Patterson Memorial State Recreation Site and Beachside Sate Recreation Site, the inundated strip is about 0.4 miles wide and includes Highway 101, the Yachats Rural Fire Protection District Station, and most of the residential area. Many east-west roads reach safety; however, there are several dead ends with marsh preventing passage to high ground farther east. We point this out to emphasize the need to think about and practice evacuation routes ahead of time. As elsewhere in the South County area, the tsunami reaches the beach in ~26 minutes and floods the region within 10 minutes (**Figure 3-42**).

**Figure 3-43** presents BTW results for the base run. Two small bridges are assumed to be impassable after the earthquake: Ocean Hills Dr near Governor Patterson (**Figure 3-43, left**) and Highway 101 over Big Creek near Burl Ln (**Figure 3-43, right**). Unlike the Alsea Bay bridge or Lint Slough bridge, these bridges cross minor bodies of water/wetlands, and it may be the case that evacuation will still be possible over or around the structures even if they fail. Results show that even without those bridges, however, successful evacuation can be achieved at a ***slow walk*** or ***walk*** (4 fps or 2.7 mph). Evacuation flow zones are presented in **Figure 3-44**.

**Figure 3-42. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake in the area of (left) Governor Patterson and (right) Beachside state recreation areas.**

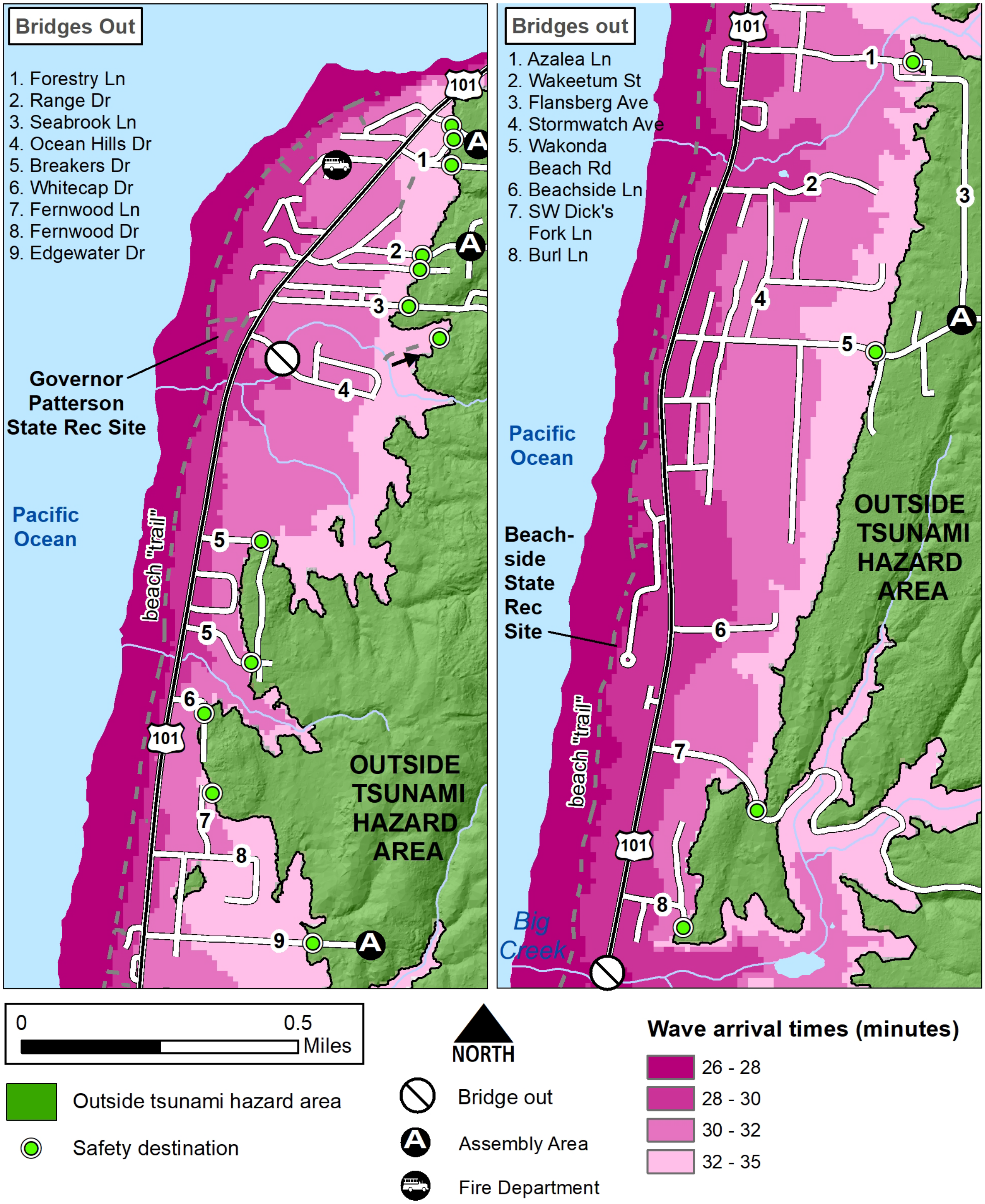


**Figure 3-43. Beat the Wave modeling of base scenario in (left) Governor Patterson and (right) Beachside state recreation areas.**

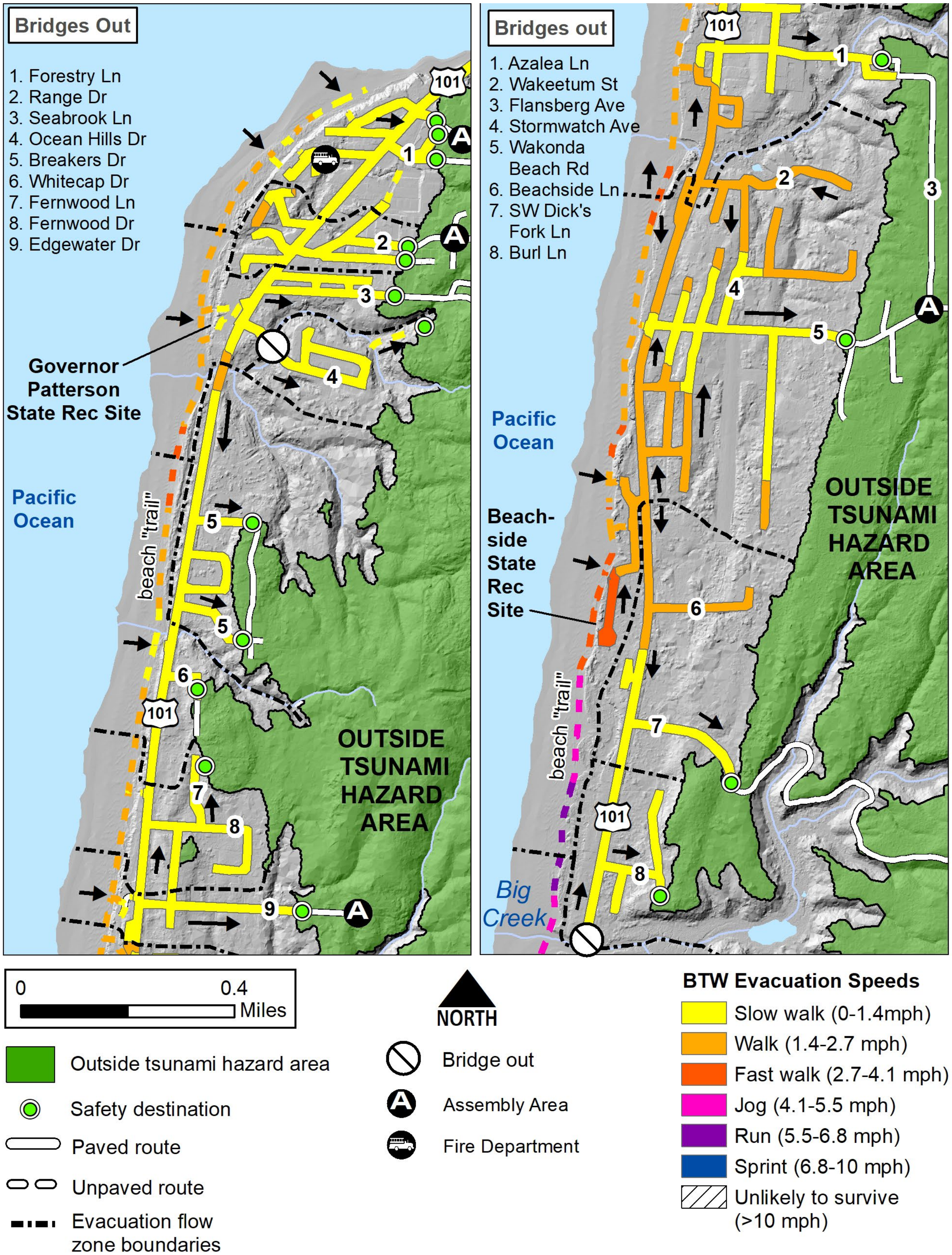
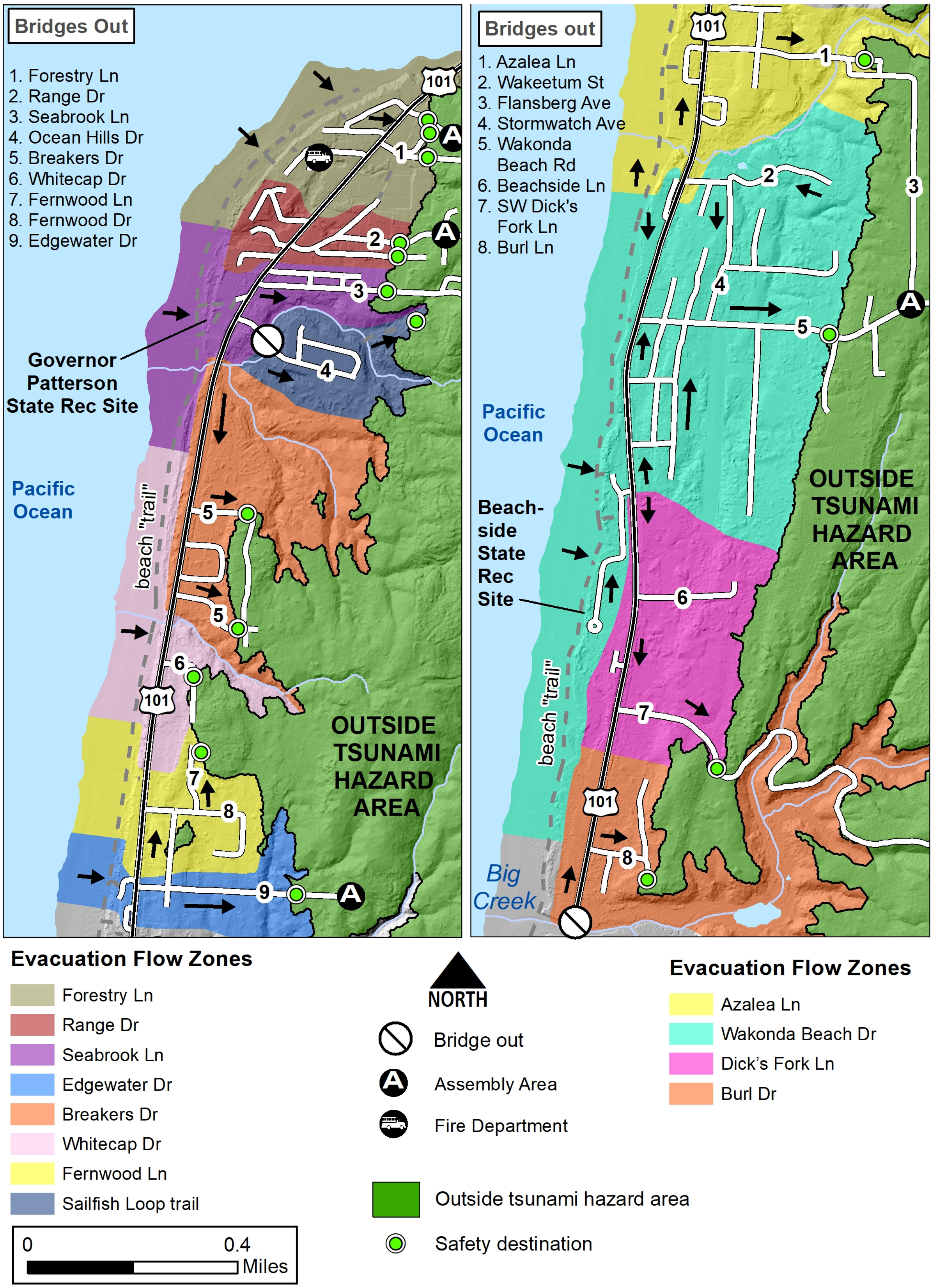


**Figure 3-44. Evacuation flow zones (base scenario) for (left) Governor Patterson and (right) Beachside state recreation areas.**



#### *3.1.3.7 Tillicum Beach*

The Tillicum Beach area south of Big Creek has a wider zone of inundation and significantly fewer roads leading to high ground than do the Governor Patterson and Beachside areas. Tsunami wave arrivals are the same: 26 minutes after CSZ earthquake shaking begins, the tsunami will arrive on the beach; inundation will be complete within another 10 minutes (**Figure 3-45, left**).

Results for a base run include the assumed failure of the Highway 101 bridge over Big Creek (**Figure 3-46, left**). The status of the Highway 101 bridge over Big Creek is more important for evacuees south of the bridge compared to those to the north. If this bridge is impassable, the potentially high number of evacuees from Tillicum Beach Campground and Angell Job Corps Civilian Conservation Center must travel at a ***fast walk*** (6 fps or 4.1 mph) for ~0.8 miles to reach high ground on NE Blodgett Rd. For comparison, if that bridge remains available, these evacuees can travel at a ***walk*** for ~0.6 miles and reach high ground on SW Burl Ln (**Figure 3-46, right**). The “bridge in” scenario represents a hypothetical retrofit of the Big Creek Bridge or simply the ability to evacuate across Big Creek regardless of bridge condition. Evacuees on all other roads in this area can reach safety at a ***walk***. Evacuation flow zones for the base run are presented in **Figure 3-45.**

**Figure 3-45. (left) Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake in Tillicum Beach area. (right) Evacuation flow zones (base scenario) for Tillicum Beach area. Base run assumes the Big Creek bridge is not available for evacuation.**

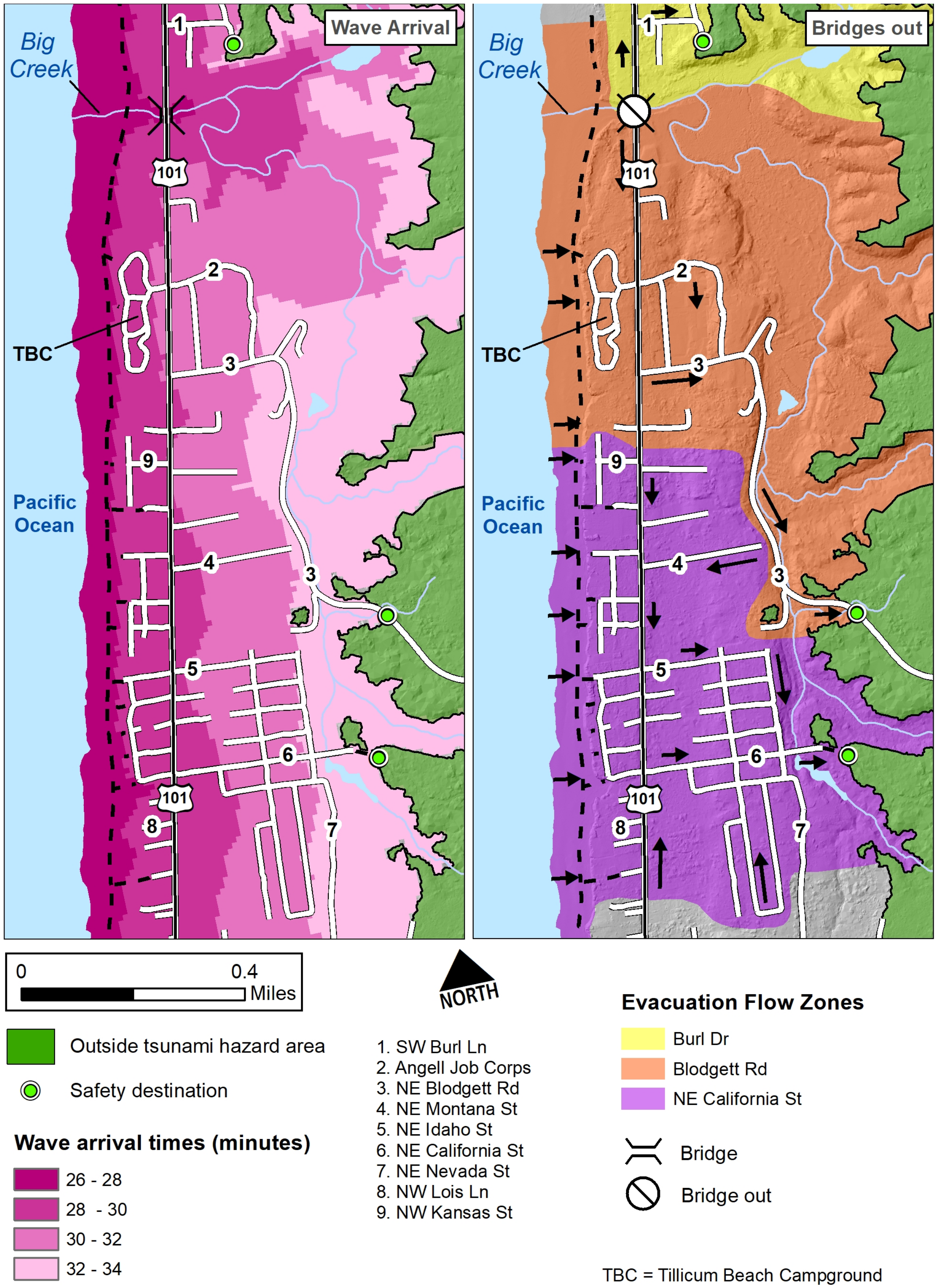
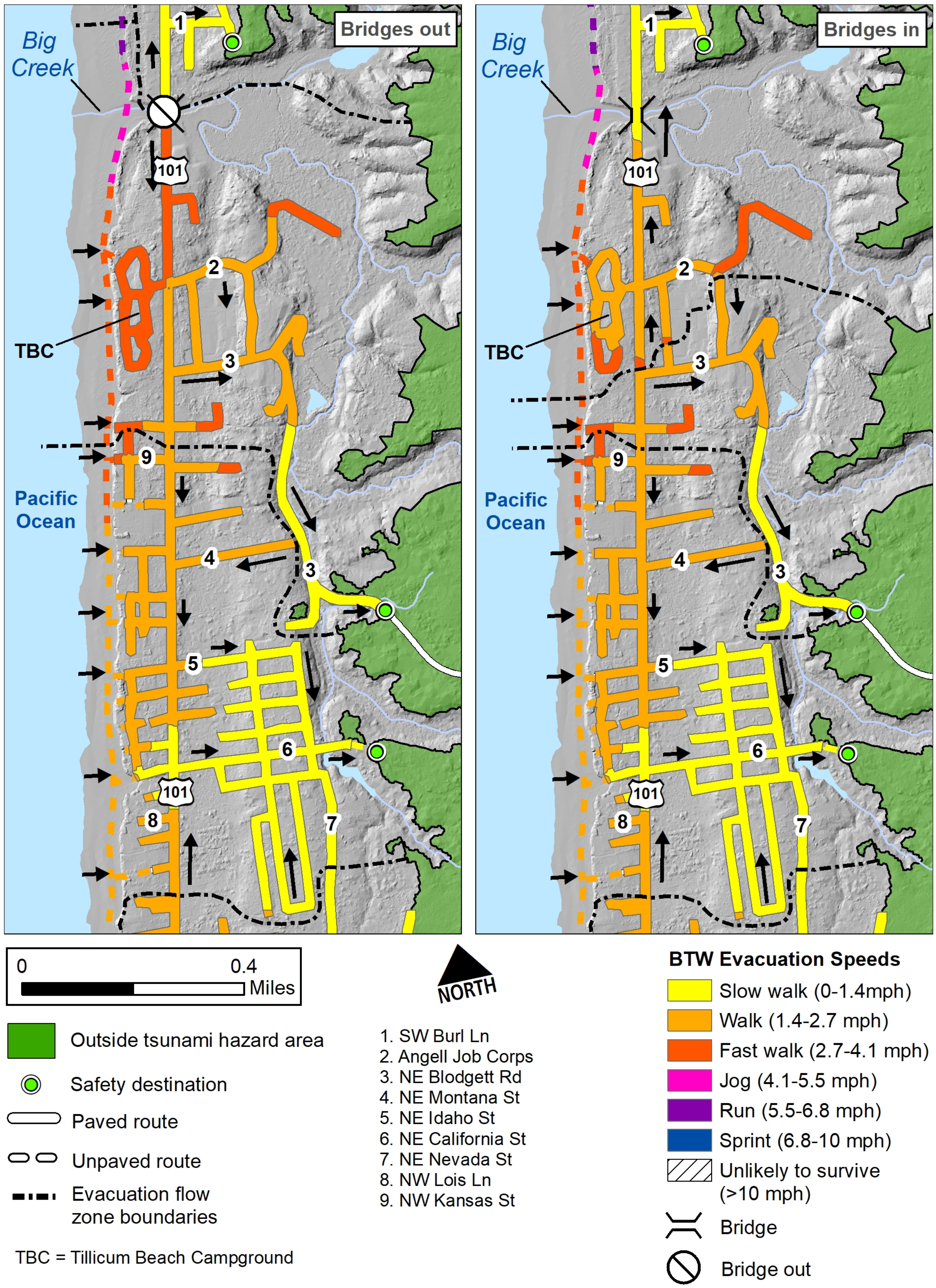


**Figure 3-46. Beat the Wave modeling of base scenario in Tillicum Beach area. Base run assumes the Big Creek bridge is not available for evacuation.**



#### *3.1.3.8 Yachats North*

North Yachats, from Camp One St to Starr Creek Dr, is expected to be completely inundated by an XXL tsunami; however, these two streets and several others extend across a marsh that backs the development so that evacuees can reach safety. Tsunami wave arrivals are presented in **Figure 3-47**. BTW results including minimum walking speeds and evacuation flow zones are shown in **Figure 3-48**. Almost everyone can reach safety by traveling at a ***walk*** (4 fps or 2.7 mph), but the presence of dead-end streets make it especially important to know which routes lead to safety.

**Figure 3-47. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake in North Yachats.**

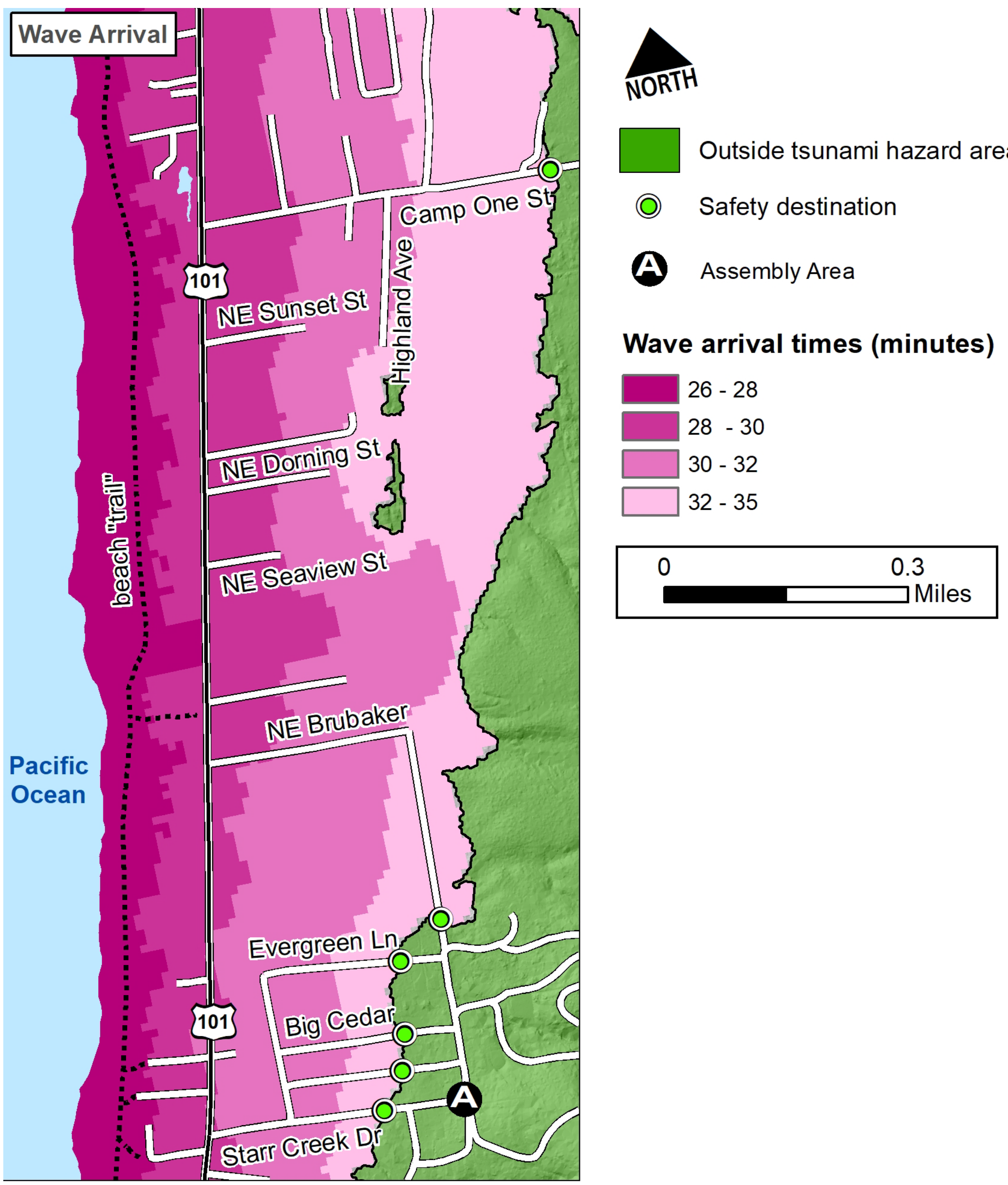
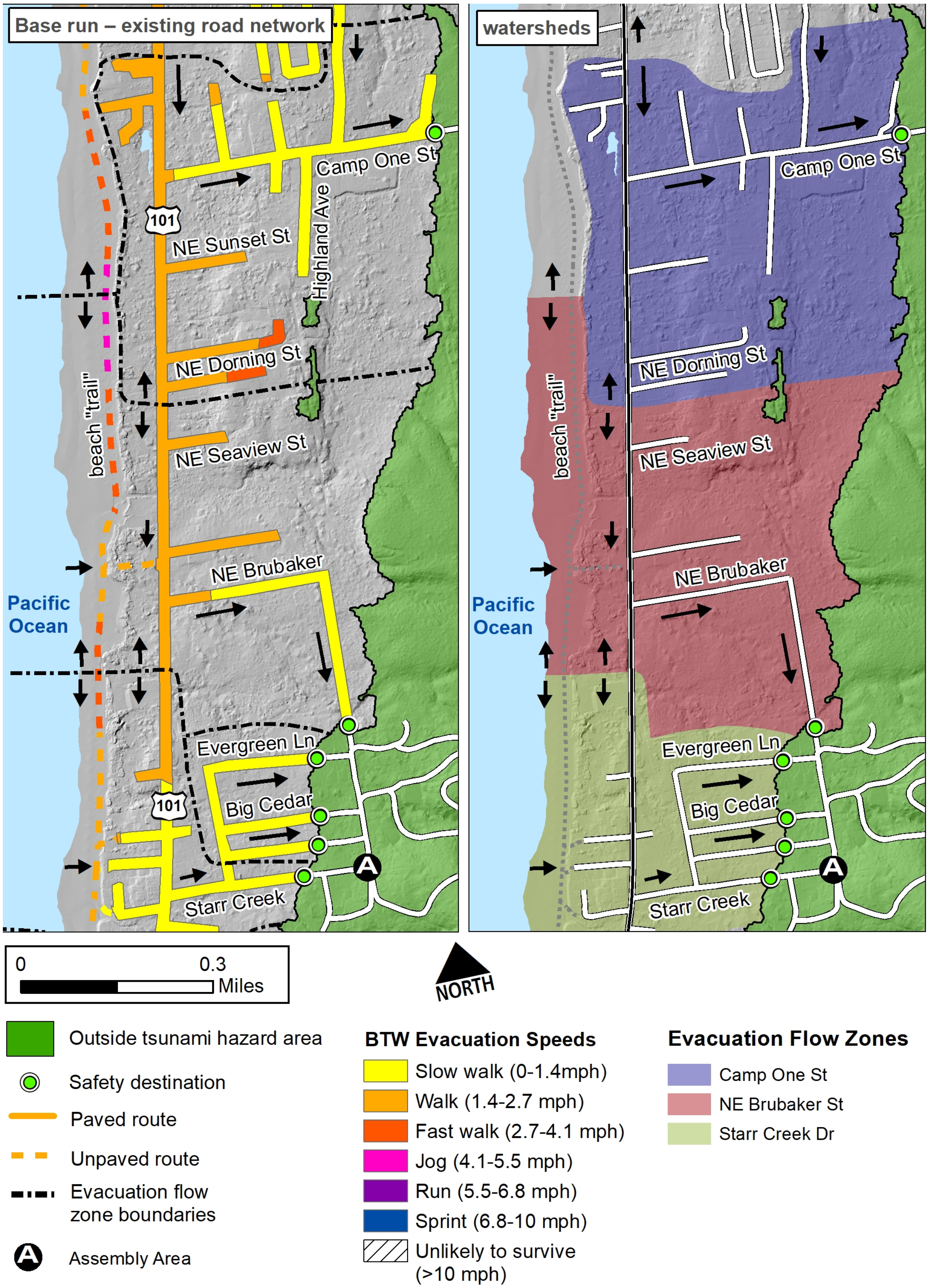


**Figure 3-48. Beat the Wave modeling in North Yachats for the base scenario. (left) Colors on top of the road network reflect minimum BTW walking speeds. Black dashed lines define evacuation flow zone boundaries. (right) Evacuation flow zones shown as colored polygons instead of black dashed lines.**



#### *3.1.3.9 Yachats*

Although much of Yachats resides within the XXL inundation zone, the high density of streets that rapidly rise uphill to safety result in some of the lowest evacuation walking speeds in the county. The Yachats fire station is within the inundation zone, but the community is currently relocating it to a new site outside the zone. The first tsunami wave arrives in ~26 minutes and sweeps across Yachats in ~4 minutes (**Figure 3-49**). **Figure 3-50** shows that all of Yachats can evacuate at a minimum BTW walking speed of ***slow walk*** (2 fps or 1.4 mph).

**Figure 3-49. Illustration of tsunami wave arrivals after XXL Cascadia subduction zone earthquake in Yachats.**

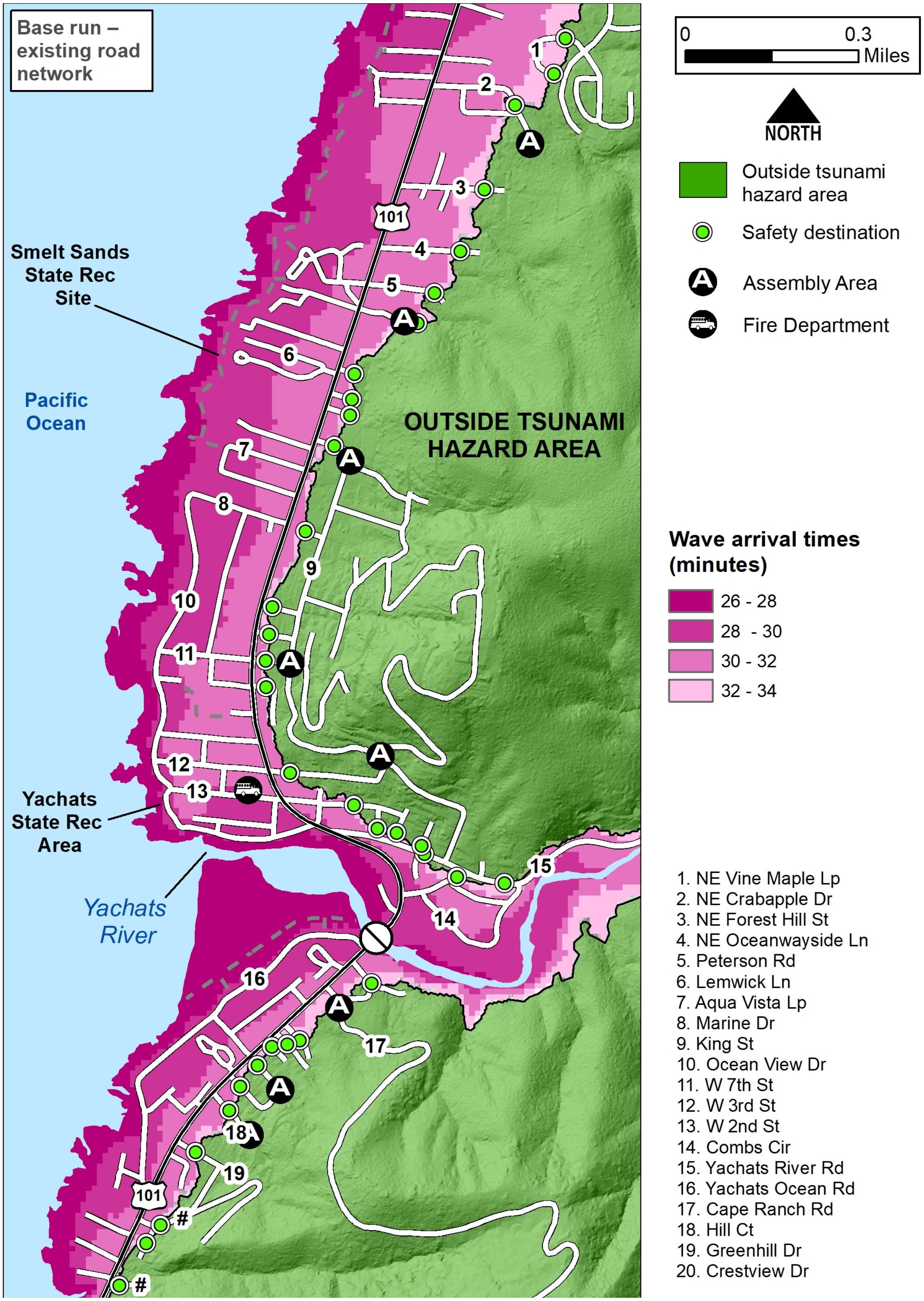
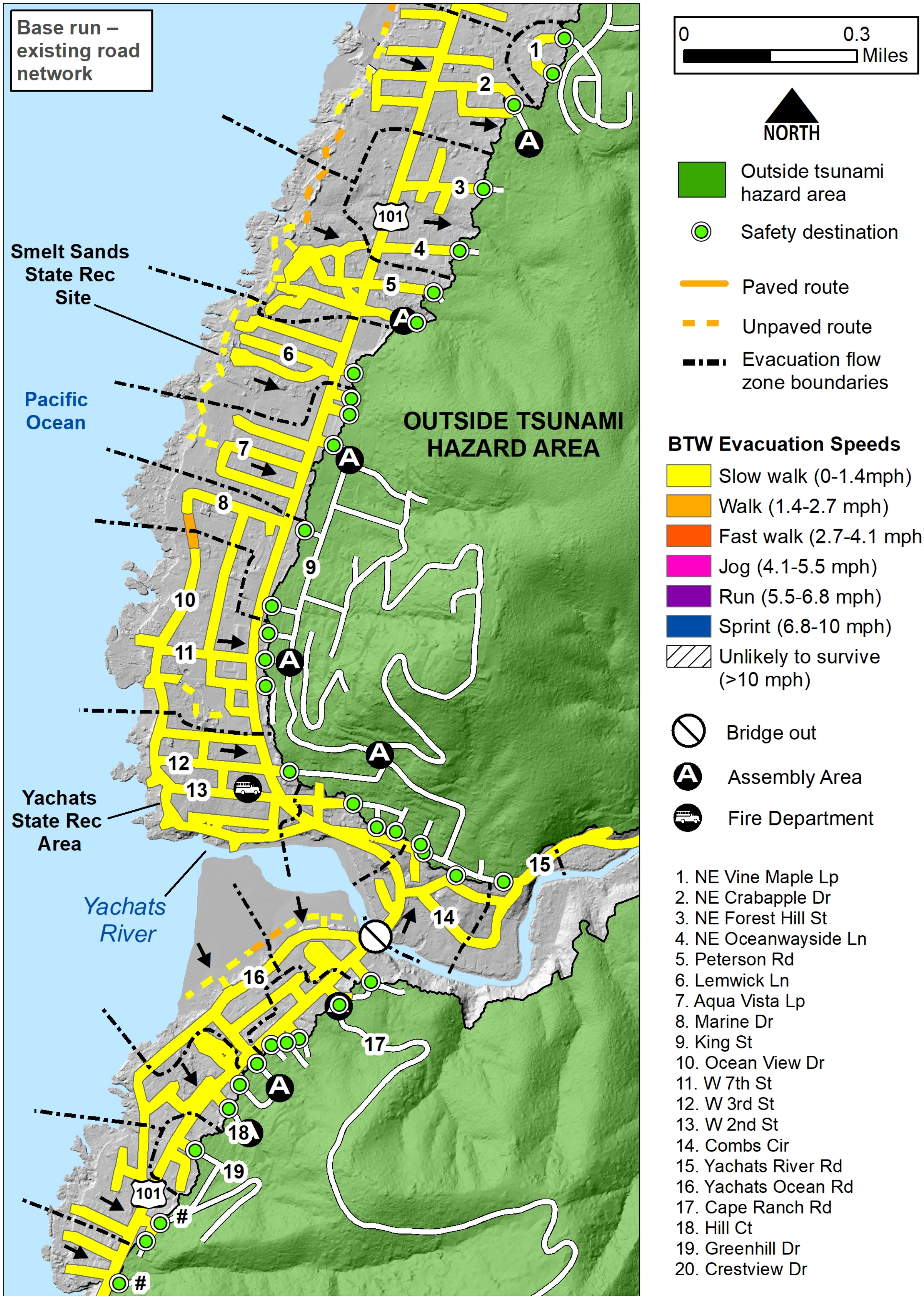


**Figure 3-50. Beat the Wave modeling in Yachats for the base scenario. Colors on top of the road network reflect <u>minimum BTW walking speeds</u>. Black dashed lines define evacuation flow zone boundaries.**



## 3.2 Socioeconomic analysis

Many Lincoln County communities have significant percentages of buildings, residents, and jobs within the tsunami zone. These present evacuation, response, and recovery challenges. In this section we provide socioeconomic perspectives of three Lincoln County communities (Lincoln Beach census-designated place (CDP) and the cities of Waldport and Yachats—**Figure 3-51**, **Figure 3-52**, and **Figure 3-53**, respectively) analyzed in this report. The Bayshore community north of Waldport is not recognized in the U.S. Census Bureau's 2010 CDP designations. The socioeconomic characteristics of Lincoln City and Newport relative to a tsunami hazard will be discussed in the results of another DOGAMI study underway (John Bauer, oral communication, 2019) so are not discussed here.

**Figure 3-51. Lincoln Beach census-designated place (CDP), showing buildings and XXL tsunami zone. Lincoln City is north of Lincoln Beach CDP. Tsunami XXL zone from Priest and others (2013b). CDP and city boundaries from U.S. Census Bureau (2010). Building footprints from Microsoft U.S. Building Footprints (https://github.com/microsoft/USBuildingFootprints).**

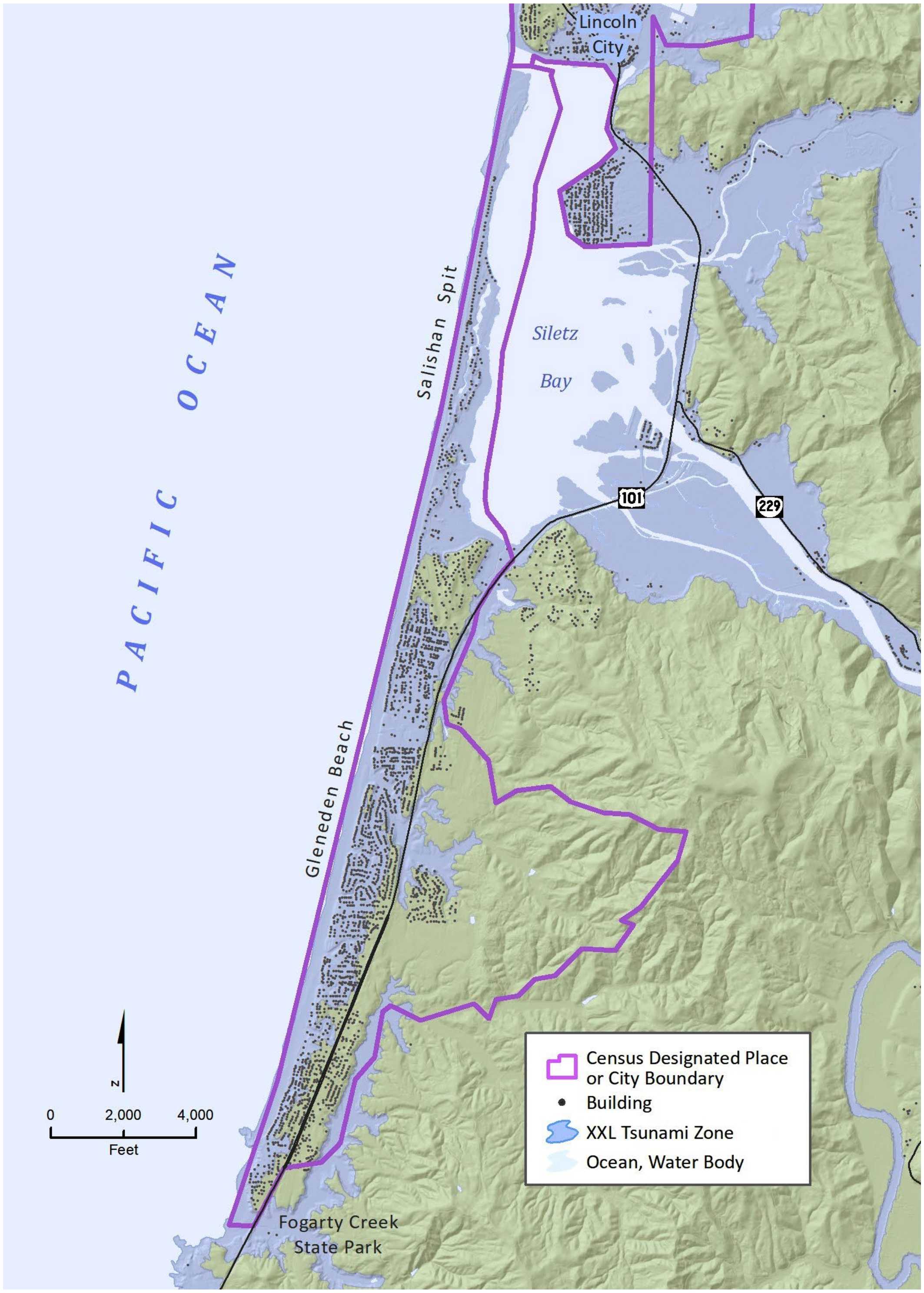


**Figure 3-52. City of Waldport, showing buildings, roads, and XXL tsunami zone. XXL tsunami zone from Priest and others (2013b). City boundary from U.S. Census Bureau (2010). Building footprints from Microsoft U.S. Building Footprints (https://github.com/microsoft/USBuildingFootprints).**

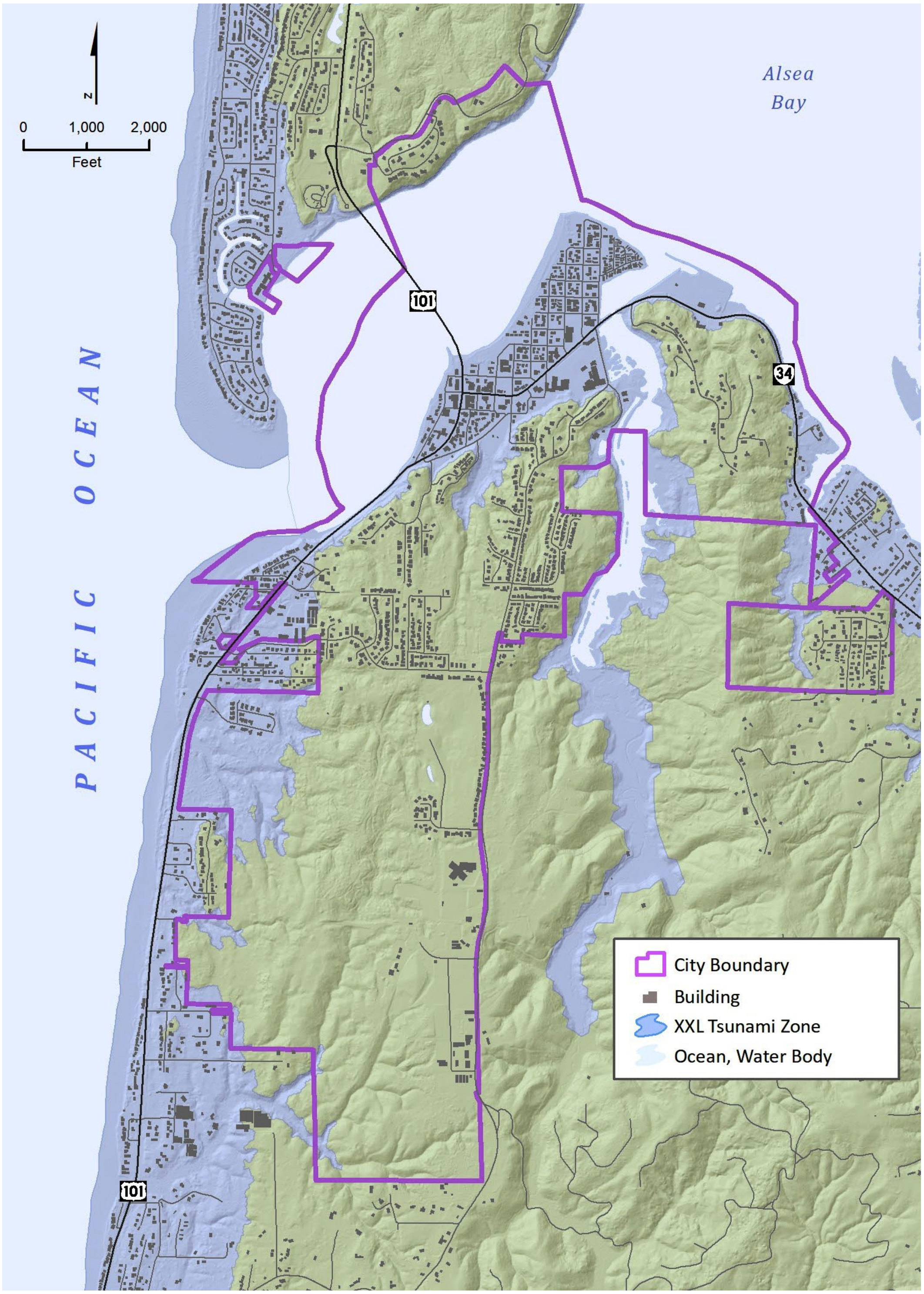
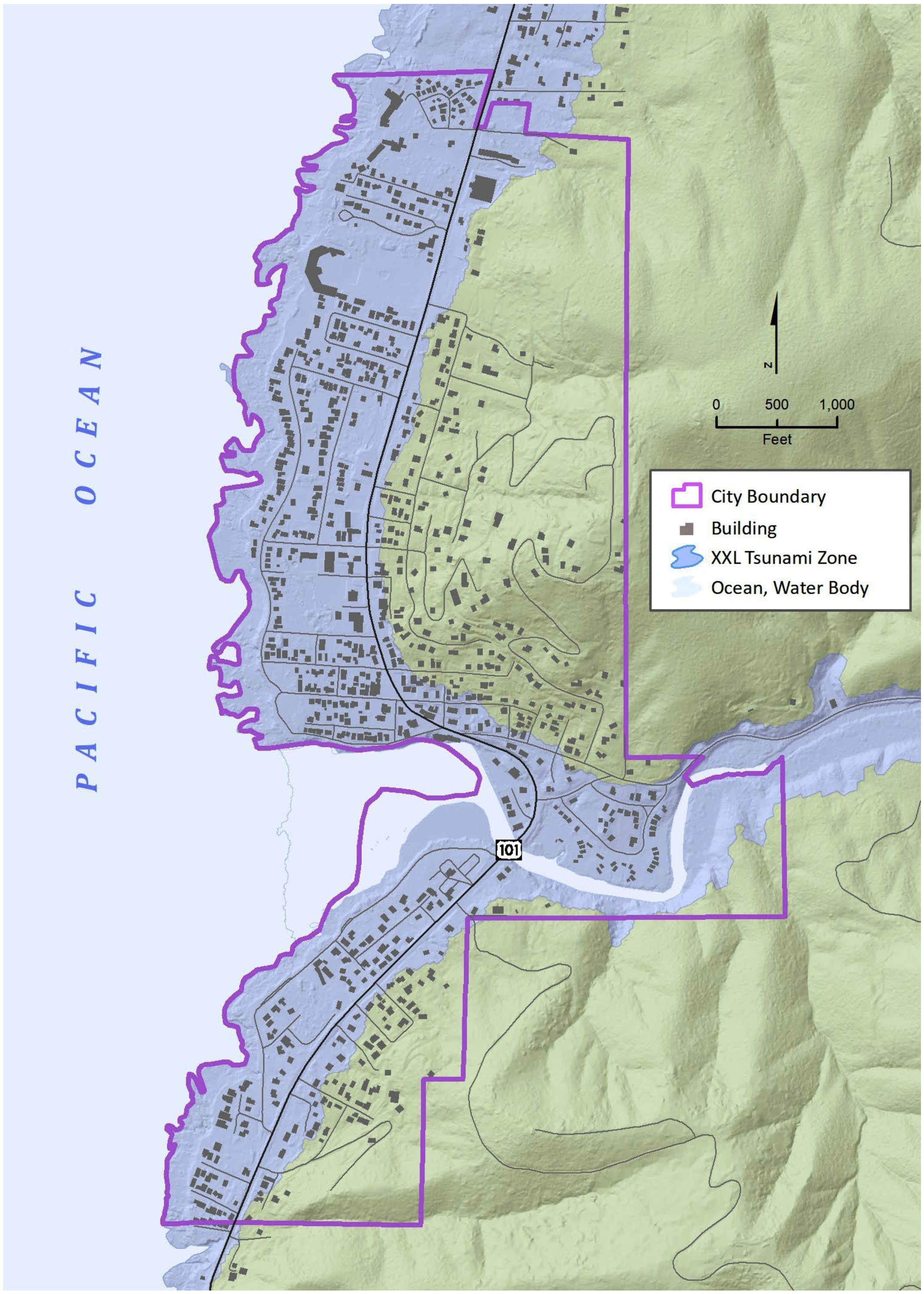


**Figure 3-53. City of Yachats, showing buildings, roads, and XXL tsunami zone. XXL tsunami zone from Priest and others (2013b). City boundary from U.S. Census Bureau (2010). Building footprints from Microsoft U.S. Building Footprints (https://github.com/microsoft/USBuildingFootprints).**



In Lincoln County, about one in five permanent residents live in homes within the tsunami zone (**Table 3-2**, **Figure 3-54**), yet about one half of the building replacement cost in Lincoln County is associated with buildings within the tsunami zone (**Figure 3-55**). The difference can be explained as follows: commercial and industrial development patterns with relatively expensive buildings are often concentrated around or adjacent to waterfronts and harbors, and large recreation-oriented facilities and motel-type housing are often concentrated near harbors and shorelines. In addition, real estate market dynamics in Oregon are such that many residential homes within the tsunami zone are second homes or vacation rentals that do not house permanent residents.

**Table 3-2. Permanent residents residing within selected tsunami zones for several Lincoln County communities, unincorporated Lincoln County (outside of all Lincoln County cities and CDPs), and overall Lincoln County. The tsunami zones are defined by Priest and others (2013b). CDP is U.S. Census Bureau census-designated place.**

| | | Tsunami Zone | | | |
|---|---|---|---|---|---|
| | | | | XXL | |
| Community | Total Population | Medium | Large | Total | People 65 and Older |
| Lincoln Beach CDP | 1,571 | 56 | 141 | 1,119 | 428 |
| Waldport | 2,105 | 521 | 553 | 679 | 208 |
| Yachats | 745 | 56 | 292 | 557 | 237 |
| Uninc. Lincoln County * | 20,004 | 1,572 | 2,490 | 4,514 | 1,305 |
| Lincoln County Total | 48,210 | 3,618 | 5,400 | 10,439 | 3,181 |

* People outside of city limits and CDP boundaries.

Population estimates: City and county population: Portland State University Population Research Center (PRC), 2018. CDP: American Community Survey data 2013-2017 5-year estimates (U.S. Census Bureau, 2018).

**Figure 3-54. Percentage of permanent residents residing within selected tsunami zones for several Lincoln County communities, unincorporated Lincoln County (outside of all Lincoln County cities and CDPs), and overall Lincoln County. The tsunami zones are defined by Priest and others (2013b). CDP is U.S. Census Bureau census-designated place. Data based on analysis of Oregon Department of Motor Vehicles records.**

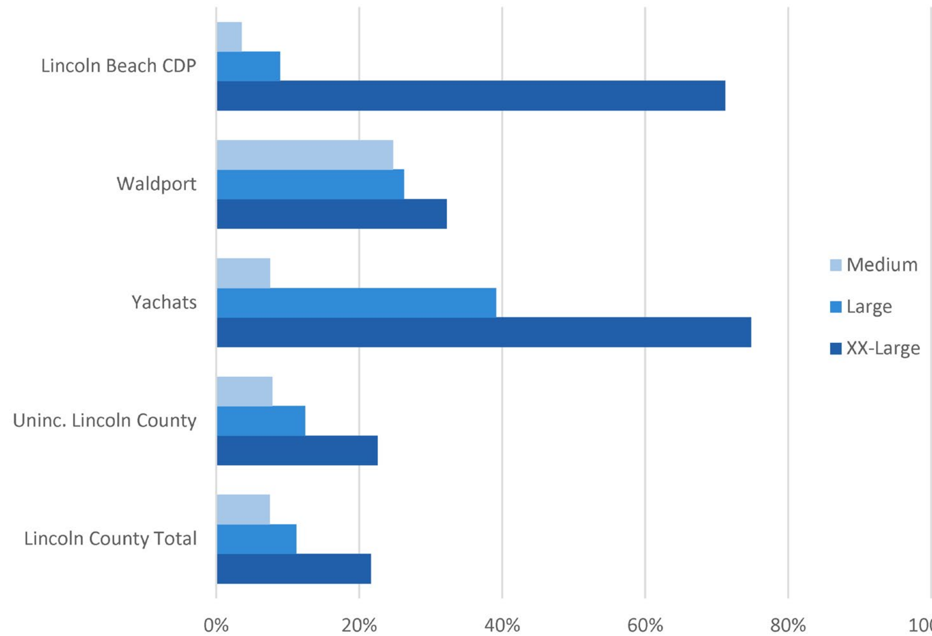
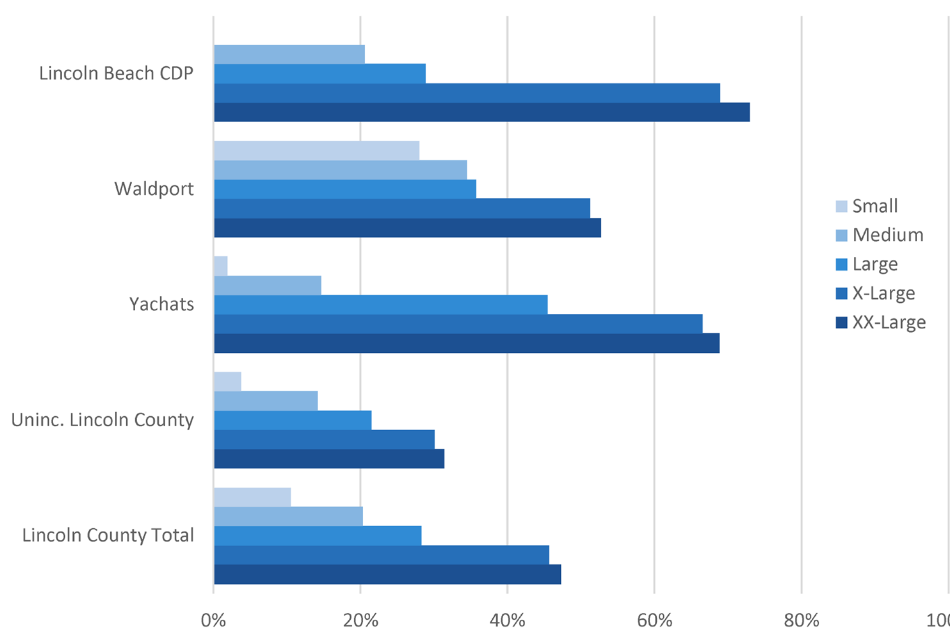



**Figure 3-55. Percentage of a community's building replacement cost within selected tsunami zones for several Lincoln County communities, unincorporated Lincoln County (outside of all Lincoln County cities and CDPs), and overall Lincoln County (M. Williams, written communication, 2019). Tsunami zones are defined by Priest and others (2013b). CDP is U.S. Census Bureau census-designated place.**

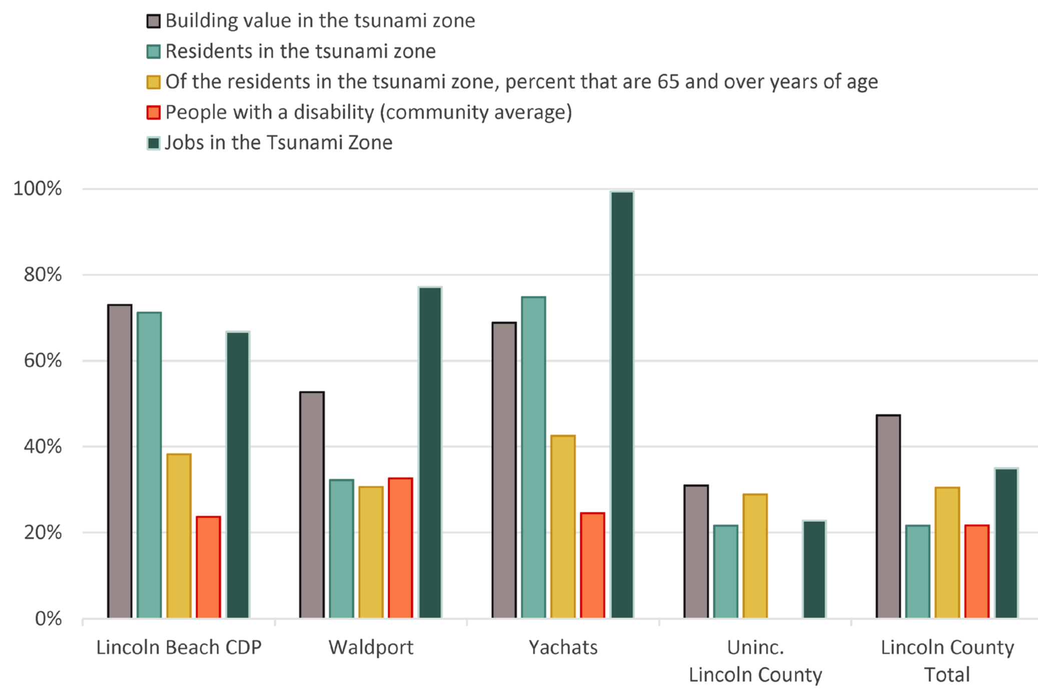


Corresponding with commercial and industrial development patterns, the percentage of the number of jobs in the tsunami zone is higher than the percentage of permanent residents within the tsunami zone (**Table 3-2**; **Figure 3-56**). A concentration of jobs within the tsunami zone can present additional disaster recovery challenges, as it is likely that places of employment will be extensively damaged or completely destroyed by a tsunami. Within many Oregon coastal communities, the Accommodation and Food Services sector (North American Industry Classification System Sector 72, https://www.census.gov/eos/www/naics/) is the largest employer by sector within the tsunami zone. Such is the case for Lincoln County overall (**Table 3-3**), Lincoln City, and Newport (John Bauer, written communication, 2019) and for Lincoln Beach CDP and Yachats. The Accommodation and Food Services sector comprises establishments providing customers with lodging and/or preparing meals, snacks, and beverages for immediate consumption. The sector includes both accommodation and food services establishments because the two activities are often combined at the same establishment (https://www.census.gov/eos/www/naics/).

The percentage of people speaking Spanish at home varies slightly by community (**Table 3-4**, **Figure 3-56**). Emergency planners can use the information to better understand the county and community diversity when crafting tsunami preparation and evacuation messages.

Tsunami casualty models commonly assume all people within a tsunami zone can evacuate in a timely manner. **Table 3-5** quantifies the number and percentage of people within each community with a disability who may have challenges mobilizing in a timely manner after an earthquake. In addition, family members or caretakers may be delayed while assisting a person with a disability. We emphasize that the percentages in **Table 3-5** are for the entire community and do not necessarily describe the population within the tsunami zone. Some communities have a larger percentage of elderly individuals (**Figure 3-56**) compared to the Lincoln County average of 30%, which can present additional evacuation challenges as the walking speeds of elderly people are on average slower than people under 65 years of age.

**Figure 3-56. Socioeconomic data for several Lincoln County communities, unincorporated Lincoln County (outside of all Lincoln County cities and CDPs [U.S. Census Bureau census-designated places]), and overall Lincoln County. Socioeconomic data sources are described in the text. The tsunami zone is defined by the XXL scenario (Priest and others, 2013b). Disability data are not available by tsunami zone but represent overall community percentage. Disability data are not available for unincorporated Lincoln County.**




The Lincoln Beach CDP encompasses the Salishan Spit and Gleneden Beach unincorporated communities south of Lincoln City (**Figure 3-54**), down to Fogarty Creek State Park. Most of the community's buildings, people, and jobs are within the tsunami zone (**Figure 3-52**, **Figure 3-56**). The permanent residents in the community's tsunami zone are slightly older on average compared to Lincoln County average of 30% (**Table 3-2**, **Figure 3-56**).

About half of Waldport residents live within the tsunami zone, yet three out of four jobs are in the tsunami zone (**Table 3-2**, **Table 3-3**, **Figure 3-52**, **Figure 3-56**). Waldport has a larger proportion of individuals with a disability (33%) compared to Lincoln County average (22%) (**Table 3-5**).

Most of Yachat's residents and building value, and nearly all the jobs in Yachats are in the tsunami zone (**Table 3-2**, **Table 3-3**, **Figure 3-53**, **Figure 3-56**).

**Table 3-3. Number of employers, employees, annual wages paid, and top employment sector for several Lincoln County communities, unincorporated Lincoln County (outside of all Lincoln County cities and CDPs [U.S. Census Bureau census-designated places]), and overall Lincoln County. The tsunami zone is the XXL scenario as defined by Priest and others (2013b).**

| | Employers | | Employees | | Top Employment Sector in Tsunami Zone | | |
|---|---|---|---|---|---|---|---|
| | Total | Tsunami Zone | Total | Tsunami Zone | % of Jobs in Tsunami Zone for Given Sector | NAICS Code | NAICS Category+ |
| Lincoln Beach CDP | 59 | 34 | 481 | 321 | 64% | 72 | Accommodation and Food Services |
| Waldport | 100 | 74 | 591 | 456 | 26% | 44 | Retail Trade |
| Yachats | 40 | 37 | 478 | 475 | 69% | 72 | Accommodation and Food Services |
| Uninc. Lincoln County* | 424 | 109 | 1,959 | 446 | 20% | 72 | Accommodation and Food Services |
| Lincoln County | 1,998 | 645 | 21,488 | 7,422 | 27% | 72 | Accommodation and Food Services |

Employment data from Quarterly Census of Employment and Wages (second quarter, 2018; J. Mendez, Oregon Employment Division, written communication, September 28, 2018).

*Employers outside of *all* Lincoln County CDPs and cities.

+North American Industrial Classification System.

**Table 3-4. Number of households and households speaking Spanish for several Lincoln County communities and overall Lincoln County. CDP is U.S. Census Bureau census-designated place. The household language assigned to the housing unit is the non-English language spoken by the first person with a non-English language. It is not an estimate of limited English fluency.**

| | Total Number of Households | Number of Households Speaking Spanish | Percent of Households with Margin of Error |
|---|---|---|---|
| Lincoln Beach CDP | 849 | 16 | 1.9% ± 2.0% |
| Waldport | 970 | 9 | 0.9% ± 1.0% |
| Yachats | 344 | 13 | 3.8% ± 5.1% |
| Lincoln County | 20,674 | 1,068 | 5.2% ± 0.7% |

Data from https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2017/

**Table 3-5. Number of individuals with a disability for several Lincoln County communities and overall Lincoln County. The number of individuals is an estimate of civilian, non-institutionalized people in the community. A person with a disability may have more than one difficulty; thus, a sum of the individual difficulty categories will typically exceed the "individuals with a disability." CDP is U.S. Census Bureau census-designated place.**

| Difficulty Category | Estimate | Margin of Error |
|---|---|---|
| **Lincoln Beach CDP** | | |
| Individuals (estimate) | 1,571 | ± 20.4% |
| Individuals with a disability | 373 | 23.7% ± 7.5% |
| Hearing | 107 | 6.8% ± 4.9% |
| Vision | 11 | 0.6% ± 0.7% |
| Cognitive | 133 | 8.6% ± 4.2% |
| Ambulatory | 253 | 16.4% ± 6.4% |
| Self-care | 37 | 2.4% ± 2.0% |
| Independent Living | 101 | 6.9% ± 3.4% |
| **Waldport** | | |
| Individuals (estimate) | 2,200 | ± 14.0% |
| Individuals with a disability | 718 | 32.6% ± 8.2% |
| Hearing | 154 | 7.0% ± 2.9% |
| Vision | 77 | 7.8% ± 3.5% |
| Cognitive | 250 | 11.9% ± 5.5% |
| Ambulatory | 487 | 23.1% ± 6.1% |
| Self-care | 155 | 7.3% ± 3.1% |
| Independent Living | 207 | 11.6% ± 4.1% |
| **Yachats** | | |
| Individuals (estimate) | 662 | ± 22.1% |
| Individuals with a disability | 162 | 24.5% ± 5.9% |
| Hearing | 67 | 10.1% ± 3.9% |
| Vision | 21 | 4.5% ± 3.0% |
| Cognitive | 60 | 9.5% ± 5.6% |
| Ambulatory | 78 | 12.3% ± 5.0% |
| Self-care | 44 | 6.9% ± 3.4% |
| Independent Living | 53 | 9.1% ± 4.0% |
| **Lincoln County** | | |
| Individuals (estimate) | 46,983 | ± 0.2% |
| Individuals with a disability | 10,186 | 21.7% ± 1.1% |
| Hearing | 3,262 | 6.9% ± 0.7% |
| Vision | 1,642 | 3.5% ± 0.5% |
| Cognitive | 3,793 | 8.5% ± 0.8% |
| Ambulatory | 5,449 | 12.2% ± 1.0% |
| Self-care | 1,784 | 4.0% ± 0.5% |
| Independent Living | 3,457 | 8.9% ± 0.9% |

Data from https://www.census.gov/acs/www/data/data-tables-and-tools/data-profiles/2017/

# 4.0 CONCLUSIONS AND RECOMMENDATIONS

This investigation provides a quantitative assessment of evacuation difficulty in selected communities of coastal Lincoln County. The investigation implemented the Beat the Wave (BTW) approach to evacuation analysis developed by Priest and others (2015, 2016), with a major refinement in that we can now account for variable speeds along a route due to differences in the route characteristics (e.g., flat vs. steep, loose sand vs. paved). As a result, the BTW approach accomplishes in a single map what would require multiple maps in other approaches such as that of Wood and Schmidtlein (2012). In contrast, the single-evacuation-speed approach of Wood and Schmidtlein (2012) is more practical for regional analyses or where wave arrival times are not known.

The results of this study demonstrate that evacuation of the studied Lincoln County coastal communities in response to a maximum considered (XXL) Cascadia Subduction Zone tsunami is attainable with the notable exception of Cutler City and Siletz Spit, where moderate to high evacuation speeds are needed to survive. In these locations, a robust education program and wayfinding signage is paramount to reduce evacuation delays and direct evacuation along the shortest route possible. Vertical evacuation is another mitigation option because of the scarcity of natural high ground (outside XXL) in the immediate vicinity. A large enough vertical evacuation structure (e.g., a berm or building) capable of holding the estimated number of people in the relevant evacuation flow zone would need to be built to a sufficient height. We recommend further evaluation to assess the cost versus benefits of this option.

Regardless of walking speeds, physical limitations, and mitigation considerations, wayfinding through adequately spaced signage, battery-operated lighting, and other means is essential to survival. Even in areas where safety is nearby and all populations appear likely to survive, confusion about where to go will make the difference between life and death. Clear and visible signage placed in key locations is extremely important, especially for areas likely to experience large numbers of visitors. We also encourage individuals to practice their evacuation route to determine what works for them. It is only through quick, instinctive evacuation that lives will be saved. This can be achieved through ongoing education programs with a focus on regular community-wide evacuation drills (e.g., Connor, 2005).

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